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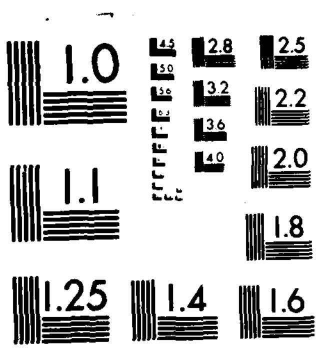

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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AD A129309

Preliminary Cost Benefit Assessment of Systems for Detection of Hazardous Weather

Volume II: Appendices

U.S. Department of Transportation
Federal Aviation Administration

Office of Aviation Policy and Plans
Washington, D.C. 20590

FAA-APO-81-8

July 1981

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Technical Report Documentation Page

1. Report No. FAA-APO-81-8	2. Government Accession No. AD-A129309	3. Recipient's Catalog No.
4. Title and Subtitle PRELIMINARY COST BENEFIT ASSESSMENT OF SYSTEMS FOR DETECTION OF HAZARDOUS WEATHER Volume II: Appendices		5. Report Date July 1981
		6. Performing Organization Code
7. Author(s) John T. Willis, Edmund Bromley, Jr., John W. Connolly		8. Performing Organization Report No.
9. Performing Organization Name and Address Sonicraft, Inc. 4600 Duke St. Alexandria, VA 22304		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA01-80-Y-30550
12. Sponsoring Agency Name and Address Office of Aviation Policy and Plans Federal Aviation Administration 800 Independence Avenue, SW Washington, D. C. 20590		13. Type of Report and Period Covered
		14. Sponsoring Agency Code APO-230
15. Supplementary Notes		

16. Abstract

Radar information on the location, intensity, and movement of hazardous weather activity, is required by the Departments of Transportation, Defense, and Commerce. The three agencies have combined to develop a common, new radar system called NEXRAD, for NEXt generation RADar. The current system lacks capability to detect wind related weather phenomena, and the new system is expected to use Doppler techniques, solid state technology, and improved processing. This report makes a preliminary assessment of costs and benefits of the NEXRAD program, concluding that the program is cost beneficial, but that not enough is known about the new system's capability to discriminate among alternative numbers and sophistication of radars in the system.

Data on losses are reported for nine separate weather hazards: floods, tornadoes, thunderstorms, hurricanes, windstorms, severe winter storms, turbulence, icing, and hail. Estimates are made of those losses avoidable with the new system.

17. Key Words Doppler, Radar Costs, Benefits Weather, Economic, Aviation, Military	18. Distribution Statement Document is available to the U. S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	124	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

APPENDICES

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APPENDICES

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APPENDIX A

TODAYS WEATHER RADAR SYSTEM

1. GENERAL

The existing weather radar system used for severe storm detection is divided into two categories:

- o A basic weather radar network, consisting of 51 WSR-57 radars and 5 WSR-74S radars, operated by the National Weather Service (NWS). In addition, 2 FPS-77 radars, operated by Air Weather Service (AWS) and 22 Air Traffic Control radars, operated by the FAA, whose primary purpose is to detect aircraft for Air Traffic Control purposes. The weather detection capability of these radars, although limited, is used in the national system.

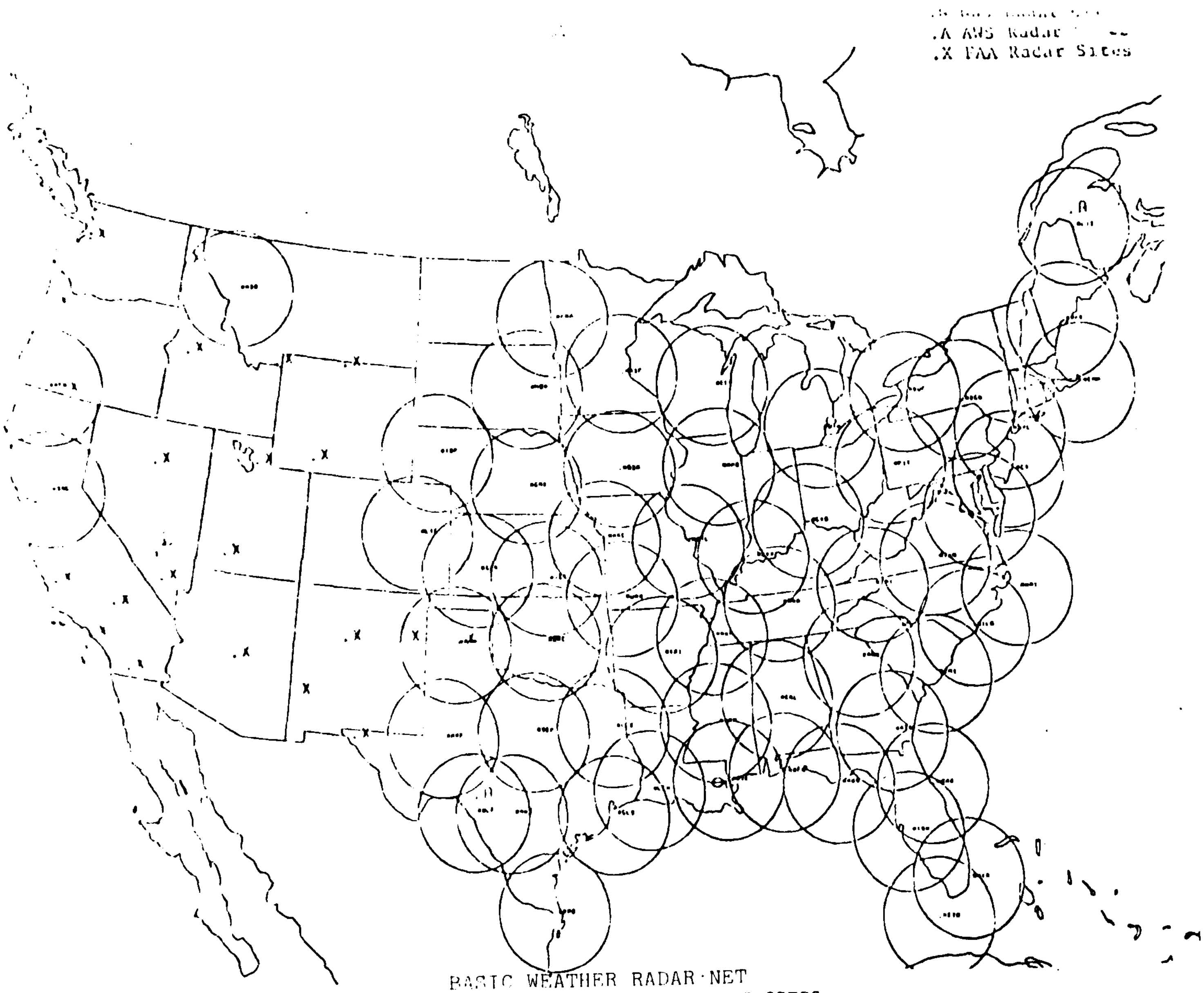
  Figure II-1 (repeated here) shows the location of the basic network radars.

- o Local warning radars are operated by NWS, AWS, and the Navy, as an addition to the basic network in areas of high severe storm incidence.

  Figure II-2 (repeated here) shows the location of the local warning radars.

2. CHARACTERISTICS OF WEATHER RADARS

Table A-1 lists the characteristics of the basic and local warning radars in use. Figure A-1 and A-2 depict the age of the WSR-57 radars and the WSR-74 local warning radars.



BASIC WEATHER RADAR NET
56-NWS, 2-AWS, 22-FAA RADAR SITES

FIGURE II-1

Notes:
... ance circles are around NWS & ... sites. They show the

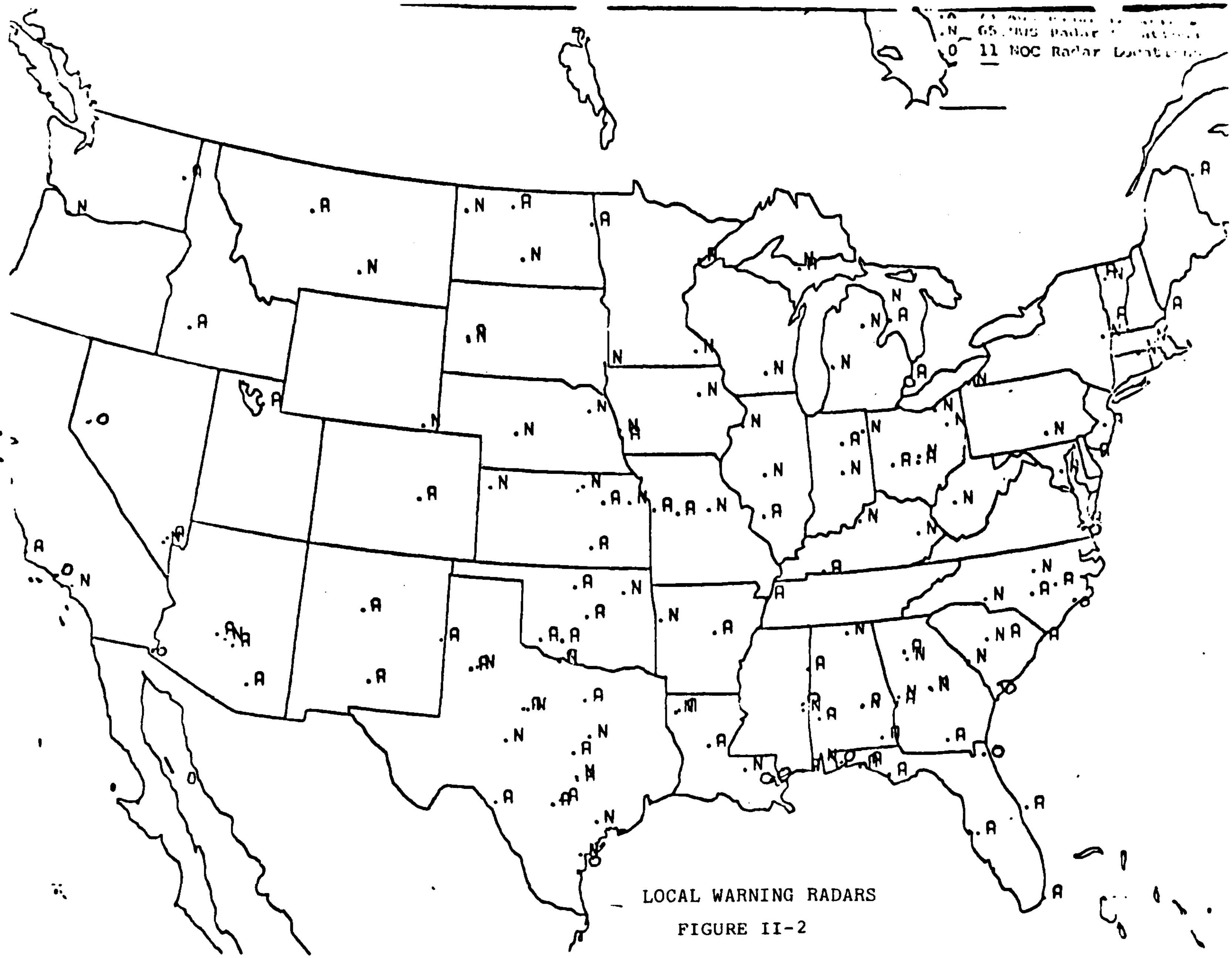
3. WEATHER RADAR COSTS

Accurate records on capital costs for weather radars are not available. An average cost was developed for each type of weather radar now used by the NWS. This table illustrates the method used to determine these average costs:

CY Year Acquired	Total Cost	WSR - 57 # Units Acquired	Aver. Cost Per Unit
1959	$1,710,053	14	$122,147
1960	1,442,712	11	131,156
1961	121,819	1	121,819
1966	288,918	2	144,459
1967	435,725	3	145,242
1969	1,240,750	8	155,094
1970	316,042	2	158,021
1977	120,000	1	120,000
TOTAL	$5,676,019	42	$133,143

Note that this assumes a constant value of the dollar.

Since there are 58 WSR-57's in the inventory, the capital cost computed on that average is $7,722,294.



LOCAL WARNING RADARS

FIGURE II-2

TABLE A-1

COMPARISON OF WEATHER RADARS

Type	Primary User	Wave-Length	Pulse Duration and PRF	Peak Transmitted Power	Type of Antenna	Beam Width	Type of Sweep	Presentation	PPI Range	Ranging Accuracy
WSR-57	NWS	10.3 cm	0.5 μsec--545 pps 4 μsec--164 pps	410 kw	12' parabola	2^{o}	Automatic and manual in horizontal vertical, either direction	PPI, off-center, PPI, RHI, R, A	250 nmi	$\pm$0.5%
FPS-106 F[illegible] F[illegible]-77V	Navy Navy AF	5.3 cm 5.4 cm	2 μsec--324 pps	300 kw 250 kw	8' parabola	1.6^{o}	Automatic and manual in azimuth and elevation 5 rpm	PPI, R, A, RHI	200 nmi	$\pm$0.5% at maximum range
[illegible]-74S	NWS	10.4 cm	1 μsec--545 pps 4 μsec--164 pps	556 kw	12' parabola	2^{o}	Automatic and manual in horizontal, manual in vertical, either direction	PPI, RHI, A	450 km	$\pm$0.5%
WSR-74C	NWS	5.4 cm	3 μsec--266 pps	250 kw	8' parabola	1.6^{o}	Automatic and manual in horizontal, manual in vertical, either direction	PPI, RHI, A	450 km	$\pm$0.5%
FPS-20 FPS-67	AF FAA	23 cm	6 μsec--360 pps	5,000 kw	40' wide 16' high	1.3^{o} az. 22^{o} vert.	Automatic in azimuth	PPI	250 nmi	$\pm$1 mi.
ARSR-1E	FAA	23 cm	2 μsec--360 pps	5,000 kw	40' wide 11' high	1.35^{o} hor. 6.2^{o} csc^2 vert.	Automatic PPI	PPI	250 nmi	$\pm$1%
ARSR-2	FAA	23 cm	2 μsec--360 pps	5,000 kw	47' wide 23' high	1.2^{o} hor. 3.75^{o} vert.	Automatic PPI	PPI	250 nmi	$\pm$1%
FPS-103	AF	3.2 cm	2.5 μsec--400 pps	50 kw	2.5' parabola	3.6^{o}	Automatic in horizontal 15 rpm, manual in vertical	PPI	150 nmi	$\pm$1%

AGE OF EXISTING NETWORK RADARS

WSR-57 Only)

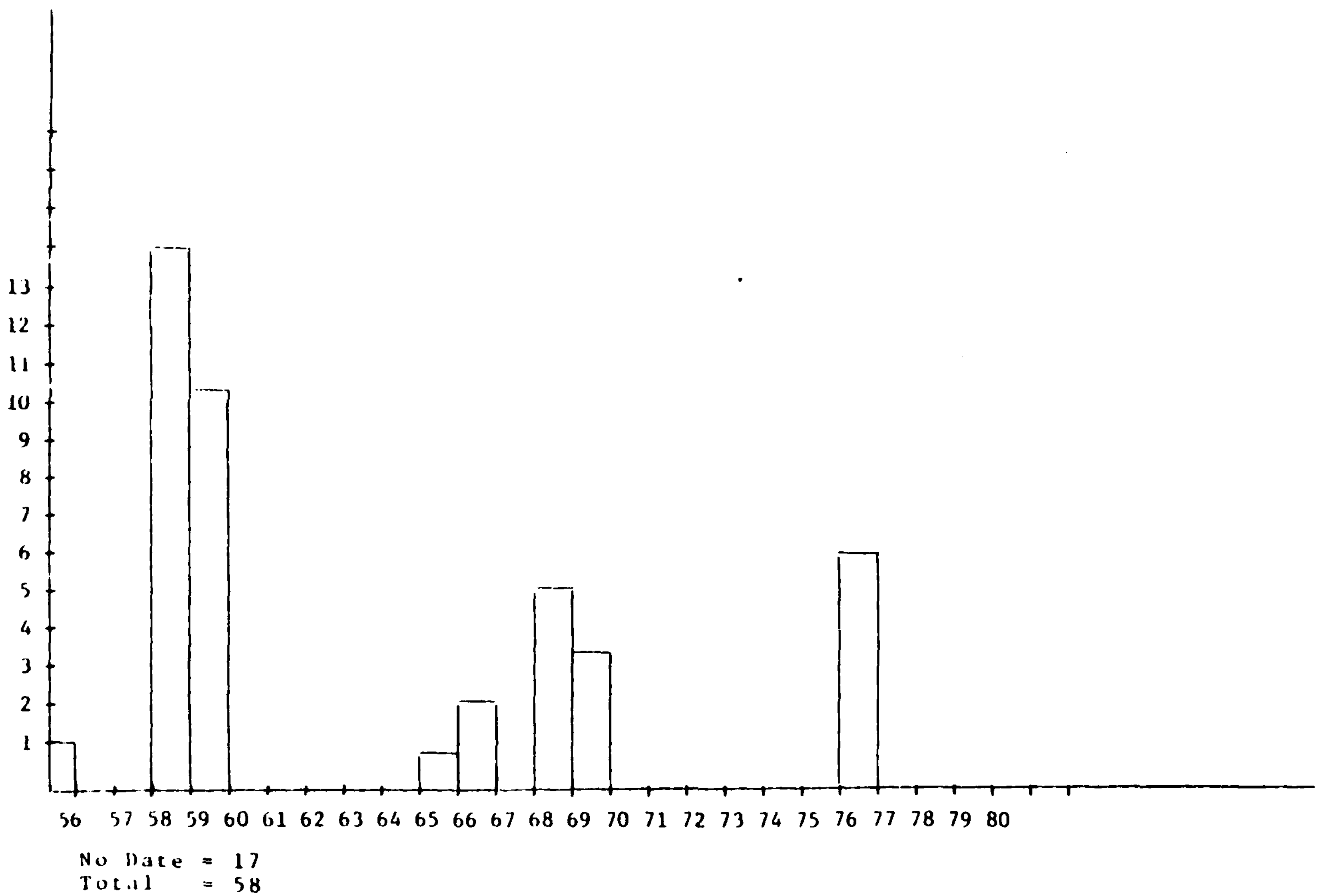


FIGURE A-1

AGE OF LOCAL WARNING RADARS

(WSR-74 Only)

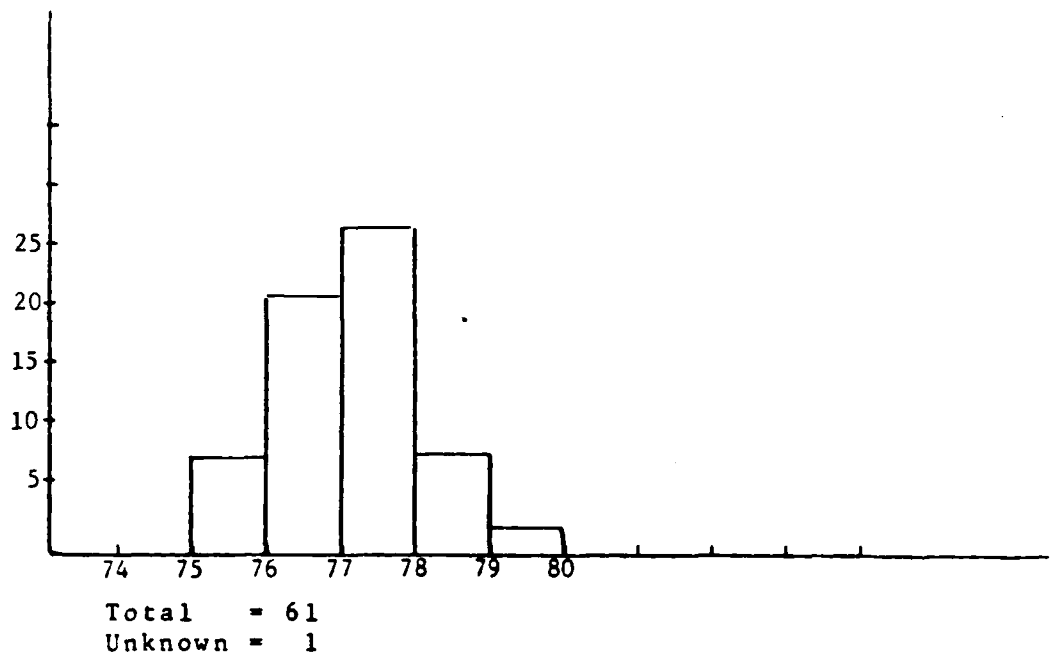


FIGURE A-2

APPENDIX B

Weather Radar --
Concepts and Some Experimental Results

Extracted from Bulletin of American Meteorological Society, October 1980, Vol. 61, No. 10, pages 1170-1171.

From: F. Ian Harris and Richard E. Carbone, Part 1: Workshop Impetus and Objectives, National Center for Atmospheric Research, Boulder, Colo.

Fundamental Concepts

Meteorological radars typically observe the atmosphere by transmitting short pulses of electromagnetic energy at wavelengths from 1 to 10 cm. Some of the transmitted energy is scattered by hydrometeors in storms or by insects, refractive index fluctuations, or radar reflective chaff in the optically clear atmosphere. For conventional radars intensity is measured, while for Doppler radars the phase and amplitude of the complex signal are detected. The rate at which the signal phase changes is directly proportional to the mean rate at which the scatterers are moving toward or away from the radar, i.e., proportional to the mean radial velocity component, V_r, of the scatterers. Each measurement of amplitude and phase represents a composite signal returned by all scatters within a measurement volume at a discrete range (Atlas, 1964). Typically, a radar with a 1^o beam looking at a rain shower at a range of 30 km "sees" roughly 10^8 particles in its $\sim 10^5$ m3 volume. Therefore, one must consider detection of the returned signal as a single realization of the intensity-weighted velocity averaged over all of the scatterers within the volume (Srivastava and Carbone, 1969) One realization of such volume-distributed targets has a relatively large uncertainty associated with it. It is necessary, therefore, to compute an average of the characteristics over roughly 10^2 radar pulses in order to obtain an estimate with acceptable uncertainty (Bohne and Srivastava, 1976; Lhermitte and Gilet, 1976). For an expanded treatment of radar principles as applied to meteorology, see Battan (1973).

The mean radial velocity that is obtained is related to the rectangular components of the mean velocity of the particles by

$$V_{ri} = u \sin\beta_i \cos \theta_i + v \cos\beta_i \cos \theta_i + W \sin \theta_i \qquad (1)$$

where β_i and θ_i are azimuth angle (measured clockwise from north) and elevation angle, respectively, and u, v and W are the eastward, northward and upward components of the mean particle velocity, respectively. The subscript "i" refers to the ith radar of an N radar multiple Doppler system. If N $\geq$3 and all radars simultaneously perform "perfect point measurements with no statistical uncertainty, then Eq. (1) can be inverted to yield solutions for u, v, and W. For N>3 the system is mathematically overdetermined and for $N<3$ it is underdetermined. In reality, the radars rarely observe the same volume at the same time, nor do they measure without statistical uncertainty. Therefore, we are able to obtain only estimates of u, v, and W, and the correctness of these estimates is dependent upon the degree to which the assumption of similitude is valid -- i.e, the degree to which all radars sample 4-dimensional space equivalently.

A further complication arises from the manner in which the data are collected. Each radar has its own spherical coordinate system that cannot coincide with that for any other radar. in order to obtain estimates of u, v, and W, it is customary, at some point in the processing, to interpolate data to a common coordinate system. This interpolation necessarily places some spatial and temporal filter on the data that confounds (and perhaps improves) the assumption of similitude.

As noted, u, v, and W are estimates of the mean scatterer velocities. For horizontal velocities it is reasonable to assume that scatters move with the mean winds. However, in the case of hydrometeors, the vertical velocity (W) is the sum of air velocity, w, and the terminal fall speed, V_t. It is, therefore, necessary to make certain assumptions about the relationship between W and w to obtain the vertical component of air motion. These assumptions may involve the relationship of V_t to the radar reflectivity factor as well as to kinematic boundary conditions.

Note

[1] Defined by the cross-sectional area of the transmitted beam times the half length of the transmitted pulse. Typically the pulse length is 300 m and the measurement volume depth is 150 m. A typical beam width is 1.0°, which is 500 m at 30 km range. In the case of a scanning antenna the measurement volume expands in the direction of scan by an appreciable fraction of a beam width.

Taken from: National Research Council, 1977, Severe Storms: Prediction, Detection, and Warning, National Academy of Sciences, Washington, D.C., pages 46-47 (with some editing).

Non-Doppler Weather Radar

Prior to the development of Doppler-equipped weather radars, non-Doppler weather radars were demonstrated to be the most valuable single tool for the monitoring of severe storms. The ability to map, in three dimensions, regions of precipitation out to some 200 km from the radar site, provides the observer with excellent information on the location and evolution of storms and quantitative estimates of rainfall that causes flash floods. Weather radar data find immediate use in systems for air traffic control, pilot briefing, and public warning.

Modern methods for processing and displaying radar data, including digitized echo strengths presented in color, can provide visually dramatic indications of precipitation areas. These new techniques can be used for the automatic synthesis of radar information with data from self-reporting rain guages. Calibration of the radar data with rain-guage measurements is important because the radar echo strength is a function of several radar parameters, as well as the raindrop number density and size distribution. As such new capabilities are introduced into routine operation, the accuracy and timeliness of warnings will increase and radar use will extend to general hydrologic purposes.

Several techniques have been used successfully in attempts to distinguish between hail and rain. With a single 10-cm radar, an echo strength implying a radar reflectivity factor greater than about log Z value of 5 at a 3-km height has been found to be a suitable criterion for identification of regions of hail. ("Z" is an empirical relationship that has been established between radar reflectivity of 'beam-filling' water droplets and the rainfall rate.)

There has been limited success in the use of operational non-Doppler weather radars for the identification of a unique tornado signature. Here, the appearance of a particular type of curved echo pattern, known as a "hook echo", is currently the best operational radar indicator of the probable existence of a tornado. However, less than half of all tornadoes are associated with recognizable hook echo patterns, and tornadoes do not always occur even when a clear hook echo is observed. Attempts to identify regions of non-tornadic severe winds and turbulence from the echo patterns have been much less successful.

Quantitative measurements of radar reflectivity using modern, economical data-processing systems have demonstrated an encouraging capability for estimating total rainfall, and thus for identifying the flash-flood potential of both hurricanes and severe local storms. While there are limitations to the accuracy with which such measurements can be made, there is little doubt that present methods can be improved sufficiently to detect potentially hazardous flash-flood conditions.

Thus, we may summarize the operational role of non-Doppler weather radar by indicating that the echo strength, which is directly related to the precipitation size and density, can be used to distinguish hail from rain and to obtain quantitative information on the distribution and intensity of rainfall and to provide an indication of storm severity. The latter are especially valuable for purposes of flash-flood warning. It should be pointed out that the echo strength, although not directly related to the turbulence, can be used to outline potential turbulent and hazardous areas of storms, albeit at the expense of as much as a 20 mile safety buffer zone.

Extracted from Bulletin of American Meteorological Society, October 1980, Vol. 61, No. 10, page 1166.

From: J. Wilson, R. Carbone, H. Baynton & R. Serafin, Operational Application of Meteorological Doppler Radar.

Conclusions and Recommendations

The JDOP experiment, which demonstrated the utility of a single Doppler radar to provide tornado warnings, was largely responsible for initiating efforts to establish a national network of Doppler radars. Our experience with Doppler radar in a wide variety of weather situations has shown that there are many additional operational applications of a single Doppler radar, thus amplifying the justification for a national network.

For widespread precipitation the vertical profile of the horizontal wind can easily be measured and monitored. Frontal boundaries that are associated with wind shifts can be located and their future position forecast. In addition to issuing tornado warnings associated with mesocyclones, Doppler radar can be used to identify regions along strong shear lines where gust front-type tornadoes may form. A frequent application should be locating gust fronts and downbursts and estimating wind speeds associated with them. Winds in the boundary layer, even during clear weather, can frequently be monitored during the warm season. An untested but promising application is the measurement of wind shears on a spatial scale critical to aircraft response. These measurements could be made with Doppler radars located at airports and directed along the approach and departure flight paths. Although hurricanes have yet to be observed by Doppler radar, it is clear that continuous monitoring of the wind field and estimation of maximum wind speed would be enormously valuable as these storms approach land.

The utility of the Doppler displays obviously depends on the experience of the observer; however, as can be seen from the examples in the paper, interpretation is not difficult. It is reasonable to expect that observers can be adequately trained with a modest effort. Observers must be aware of the limitations of the radar and must have a basic understanding of the meteorological conditions that will be observed. Range and velocity folding can greatly complicate interpretation, particularly for large convective storms. Thus, it is almost essential that operational Doppler radars employ some means to unfold velocities and remove range ambiguities. Some very promising solutions to this problem have been proposed by Doviak et al. (1978) utilizing staggered or non-uniform pulse repetition periods. It is reasonable to expect that automatic means for interpreting and identifying important features in the Doppler velocities will begin to emerge as more experience is gained. Initially, however, humans will need to play a major role in the interpretation phase.

Users should be aware that maximum wind speeds will be underestimated when they occur only at radar azimuths where there is a significant wind component normal to the radar. Most frequently this will affect maximum wind estimates in highly localized shear and convergence zones. Furthermore, these regions may on occasion escape detection when the shear is primarily in the wind component normal to the radar. The detection of mesocyclones associated with severe storms will not be affected because of the circular motion of the flow. We believe that these limitations will occur relatively infrequently and do not significantly detract from the overall operational utility of Doppler radar.

APPENDIX C

Selected Case Studies

CS-1	Waterloo, Iowa Airport Hit by 100mph Winds; Property Loss Over $3 Million, July 9, 1980
CS-2	Severe Storm Threat Cancels Army Band Concert, July 22, 1980
CS-3	Tornado Strikes Altus AFB, Oklahoma, May 20, 1977
CS-4	Hurricane Agnes Warning Support to Eglin ABF, Florida, June 18-19, 1972
CS-5	Thunderstorm Wind Gusts Damage Aircraft at Patrick AFB, Florida on 30 June 1980
CS-6	Thunderstorm Winds Damage Helicopters, Fort Hood, Texas, June 18, 1976
CS-7	Hurricane Agnes Warning Support at Tyndall AFB, Florida, June 18-19, 1972
CS-8	Tornado False Alarm, Fort Benning, Georgia
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CS-10	Severe Weather Warning Support at Vance AFB, Oklahoma
CS-11	Weather Warning Service to Andrews AFB, Maryland
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CS-13	Launch Pad Lightning Warning System, Cape Kennedy
CS-14	Value of Severe Weather Service at Laughlin AFB, Texas
CS-15	Tornado Activity, Bergstrom AFB, Texas
CS-16	Future Disaster: Miami
CS-17	Destructive Winds - Hood Canal, Washington, February 12, 1979
CS-18	Tornado Warning at Algona, Iowa, June 28, 1979.

CS-1

Waterloo, Iowa Airport Hit by 100 mph Winds
Property Loss Over $3 Million

On July 9, 1980 at 2:00 a.m., a severe thunderstorm with accompanying winds clocked at over 100 mph struck the Waterloo, Iowa airport and vicinity causing property losses in excess of $3 million.

The storm struck without warning although the National Weather Service radar was operating and had been tracking the storm previously until the storm entered the ground clutter and the intensification went undetected.

The straight-line winds from the storm, a microburst in Dr. Ted Fujita's analysis, damaged 65 homes and mobile homes, 65 private aircraft, 17 businesses and most of the 12 helicopters of the Army Aviation Group based at the airport. The aircraft and helicopters that were damaged were tied down.

In this case, with a minimum number of people on duty at 2:00 a.m., a response to protect the property even if a warning had been issued would probably not have been effective in preventing the loss.

If the storm had struck at 2:00 p.m. when personnel were on hand to respond to the warning, it is postulated that:

1. With 30 minutes advanced notice of the storm, the helicopters would have been surrounded by trucks and other vehicles to minimize the loss.

2. With one to one and one half hour notice, all helicopters would have been hangared and in this instance, the damage (over $1 million) prevented.

Source: Sonicraft File
Correspondene: Iowa Office of Disaster Services
Ms. Cheri Thomas

CS-2

Severe Storm Threat Cancels Army Band Concert

On Tuesday, July 22, 1980, the Army Band concert scheduled for 8:00 p.m. out-of-doors at the Jefferson Memorial, Washington, D.C. was cancelled. This cancellation was announced over public radio (i.e., WMAL) at 4:45 p.m. The cancellation decision seemed to be open to question as a series of thunderstorms had just moved out of the Washington, D.C. area -- skies were clearing -- at about 4:30 p.m.

However, the cancellation decision was based on the detection (around 4:00 p.m) of a line of severe thunderstorms about 100 miles west of Washington by the Andrews Air Force Base Weather Radar. The Army band commander decided on the cancellation due to expected severe weather at 6:30 p.m. and during the concert.

The benefits accrued from this decision were those costs to the band for transport, assembly and set-up and costs to the 2,000 to 3,000 concert attendees.

It was a good and correct call as it rained and thundered with associated severe weather from about 6:30 p.m. to midnight.

Source: Sonicraft File: 7/24/80

CS-3

Tornado Stikes Altus AFB, Oklahoma
May 20, 1977

"An example of tornado advisory capability was provided when a tornado struck Altus (LTS) on 20 May 1977. A list of events is as follows:

1. 1254 CST - LTS Weather Warning for hail and gusts to 45 kts.
2. 1350 CST - Marble-size hail reported at 240°/21 nmi from LTS.
3. 1356 CST - Doppler detected first shear.
4. 1400 CST - Marble-size hail reported at 200°/18 nmi from LTS.
5. 1406 CST - Doppler confirmed mesocyclone and called LTS (information not understood and therefore not used).
6. 1410 CST - Pea-size hail reported at 240°/5 nmi from LTS.
7. 1420 CST - Tornado reported at 190°/9 nmi from LTS.
8. 1421 CST - LTS Weather Warning for a tornado in the vicinity.
9. 1423 CST - 3/8 inch hail at LTS.
10. 1430 CST - Tornado 1/2 mile south of base moving NE, station evacuated.
11. 1432 CST - Tornado over runway.
12. 1445 CST - Tornado dissipated north of the base.

The Doppler 26-minute lead time, as opposed to 9 minutes by the LTS forecaster, shows the increase in warning lead time and detection capability possible from Doppler. The LTS radar did not detect a hook echo and the AWS warning was based on Civil Defense reports. Damage to the base was extensive with losses in excess of one million dollars." (Staff of JDOP; 1979) .

CS-4

Hurricane Agnes Warning Support to Eglin Air Force Base

1. Situation: Eglin AFB is located in the northwest panhandle of Florida, a region with a high threat from tropical storms during the period June to November. Maximum, but costly precautionary actions are necessary to protect aircraft, personnel, and Government property which are extremely vulnerable to effects of high winds and flooding from hurricane forces. During the period 18-19 June 1972, Hurricane Agnes approached the Florida panhandle from the Gulf of Mexico and was forecast to pass within 75 miles of Eglin. Maximum winds observed at Eglin were 41 knots. No damage or injuries were observed.

2. Support Provided: Forecast assistance in deciding not to evacuate aircraft and undertake major precautionary actions.

3. Decisions Improved:

a. Weighing the costs of major storm preparation/evacuation versus the probability of damage from winds and flooding.

b. Taking of only minimum precautionary actions.

Value Analysis

1. Cost of minimal precautionary actions: $5,000.

2. Estimated benefits:

a. Savings in cost of evacuating ADTC aircraft: $160,000.

b. Savings in cost of facilities preparation through Hurricane Condition I: $130,000.

c. Saving in lost manhours since no sheltering of personnel took place: $280,000.

3. Summary: Weather service provided the Commander at Eglin saved the Government an estimated $1/2 million in avoided evacuation and preparation costs. Had the Commander not been provided with tailored weather support, he would have been forced to take all possible precautions when confronted with a storm following the path of Agnes.

Source: Headquarters, Air Weather Service
MAC
Scott AFB, Ill.

CS-5

Thunderstorm Wind Gusts - Damage to Aircraft at Patrick AFB, Florida on 30 June 1980

The 30 June mishap which saw two OV-10s damaged by wind gusts to 84 knots associated with thunderstorms resulted in the following cost to the government:

Aircraft #67-14610	Parts:	$ 12,600.00
	Manhour Costs:	3,200.00
Aircraft #67-14606	Destroyed	480,000.00
	Total:	$495,800.00

We were not able to provide the lead time notification to our customers for these strong winds. Doppler radar with its wind display may have provided clues to the severe potential of this storm vice typical convective activity, and allowed the lead time required to protect the aircraft and reduce the damage received.

The particular storm cell that caused this damage was not the tallest or most reflective of cells depicted upon the Patrick AFB FL FPS-77 radar. A storm with tops of 59,000 MSL produced no winds as it moved over Cape Canaveral AFS north of Patrick AFB. The storm over Patrick AFB was showing tops of 35,000 MSL just before it moved over the base. It later showed maximum tops of 53,000 MSL. The point is, a Doppler radar may have distinguished severe weather producing potential of storm cells in the vicinity of Patrick AFB on 30 June 1980. (Source Ltr 15 September 1980, Parker, R.C. Maj., Met Section, Patrick AFB).

CS-6

Thunderstorm Winds Damage Helicopters, Fort Hood, Texas

1. Army helicopters are very vulnerable to strong or gusty winds during takeoff and landing. Because of this, the flying units here take precautions to limit flying whenever hazardous winds occur. In addition, storng winds can damage parked aircraft, whether or not they are tied down. We could not obtain data on wind damage to helicopters in flight, but we offer several cases where winds from thunderstorms caused damage to helicopters which were tied down but not hangared.

a. On 18 June 1976, a gust of 45 knots destroyed or damaged 28 aircraft at Hood Army Airfield. We were following the thunderstorm cell which spawned the gust on radar, and it did not appear severe. It is possible that the cell produced a small tornado, although none was sighted. This is the type of storm that a doppler radar would best be able to identify. Repair costs from this incident were about $240,000; photos taken by III Corps Aviation Safety are enclosed. These photos also illustrate that most damage occurred to aircraft parked on open ground. If our warning had correctly forecast the intensity of the storm, more aircraft may have been hangared or moved to more secure tie down areas on the runway. With a Doppler radar, we potentially could have done this.

b. On 16 October 1979, a gust of 48 knots blew over an OH-58, causing about $19,000 damage. Our radar showed this thunderstorm cell to be of only moderate intensty. Perhaps we could have "seen" the potential for damaging winds with a Doppler radar.

c. On 7 April 1980, a gust of 46 knots damaged 10 aircraft. Nine of the ten were OH-58s. Although we had issued a warning for wind gusts in the 35-49 range 80 minutes prior the damaging gust, repair costs amounted to $155,000. As with the preceeding examples, the damaged aircraft were secured on open ground. We might have been able to issue a more defninitive warning with NEXRAD.

2. A more advanced radar would enable us to pick out the most hazardous thunderstorm cell(s). Several "near misses" that we are aware of are a tornado at Burnett (30 miles southwest) on 10 March 1973, a large hail storm at Temple (35 miles east) on 5 February 1974, and a tornado at Mabry ANG Base (60 miles south) associated with hurricane Allen on 10 August 1980

Extracted from: Det. 14, 5th Weather Sqdn., AWS, letter 29 October 80.

Hurricane Agnes Warning Support at Tyndall AFB, Florida, 18-19 June 1972

Background

1. Situation: Tyndall AFB is located in the northwest panhandle of Florida, a region with a high threat from tropical storms during June to November. Without proper warning support aircraft, personel, and Government property are extremely vulnerable to the effects of high winds and flooding from hurricane forces. During the period 18-19 June 1972, Hurricane Agnes approached the Florida Panhandle from the Gulf of Mexico and was forecast by NHC to pass directly over Tyndall AFB with 100 kt max winds. Hurricane Agnes rapidly lost energy and became disorganized as it came within 100 miles of land on the morning of 19 June. Maximum estimated winds observed were 46 knots. Damage to the base and equipment was estimated at $2,500. One injury, a severed finger, was incurred by high winds slamming a car door.

2. Support Provided: Weather briefings on National Hurricane center (NHC) advisories and local tailored forecasts based on NHC advisories, local weather radar, and direct contact with WC130 storm reconnaissance aircraft.

3. Decisions Improved:

a. Declaration of base hurricane conditions (HURCON) and resultant evacuation/preparation actions:

1. Evacuation of some, but not all, aircraft.

2. Evacuation and sheltering of families living in unprotected Government quarters.

3. Sandbagging and securing of buildings and equipment.

4. Movement of AME (telemetry) trailers.

b. Timely recall of personnel.

c. Not employing excessive, costly precautions necessary for storms with greater than 75 knots.

Value Analysis:

1. Cost of weather support: Only indirect costs were expended. Hurricane warning advice and decision-assistance are only one of many services produced by the Base Weather Station.

2. Estimated cost of precautionary actions:

CS-7

Hurricane Agnes Warning Support at
Tyndall AFB, Florida, 18-19 June 1972

Background

1. Situation: Tyndall AFB is located in the northwest panhandle of Florida, a region with a high threat from tropical storms during June to November. Without proper warning support aircraft, personel, and Government property are extremely vulnerable to the effects of high winds and flooding from hurricane forces. During the period 18-19 June 1972, Hurricane Agnes approached the Florida Panhandle from the Gulf of Mexico and was forecast by NHC to pass directly over Tyndall AFB with 100 kt max winds. Hurricane Agnes rapidly lost energy and became disorganized as it came within 100 miles of land on the morning of 19 June. Maximum estimated winds observed were 46 knots. Damage to the base and equipment was estimated at $2,500. One injury, a severed finger, was incurred by high winds slamming a car door.

2. Support Provided: Weather briefings on National Hurricane center (NHC) advisories and local tailored forecasts based on NHC advisories, local weather radar, and direct contact with WC130 storm reconnaissance aircraft.

3. Decisions Improved:

a. Declaration of base hurricane conditions (HURCON) and resultant evacuation/preparation actions:

1. Evacuation of some, but not all, aircraft.

2. Evacuation and sheltering of families living in unprotected Government quarters.

3. Sandbagging and securing of buildings and equipment.

4. Movement of AME (telemetry) trailers.

b. Timely recall of personnel.

c. Not employing excessive, costly precautions necessary for storms with greater than 75 knots.

Value Analysis:

1. Cost of weather support: Only indirect costs were expended. Hurricane warning advice and decision-assistance are only one of many services produced by the Base Weather Station.

2. Estimated cost of precautionary actions:

a. Evacuation of aircraft: $53,800

b. Loss of 132.4 training hours: $7,750

c. Cost of 6,630 hours of civilian administrative leave: $34,530

d. Loss of military manpower: $88,230

e. Movement of AME trailers to higher elevation: $1,670

f. 1246 manhours expended in preparation, repair and cleanup activities: $9,000.

Total Costs: $195,000

3. Estimated Benefits:

a. Removal of AME (telemetry) trailers from beach area (where storm surge would have destroyed them): $510,000

b. Savings in not evacuating all aircraft (forecast based on local winds 75 kts or less): $53,800

c. Recoup of training hours because of only partial evacuation: $7,750

d. Timely recall of personnel resulting in savings in civilian time/pay of one-half day: $34,500

e. Estimated savings resulting from tie down of equipment, securing areas in/around buildings, and taping of numerous windows: $2,500

Total tangible benefits: $608,500

4. Summary: Using NHC advisories and local weather radar observations, the Tyndall Base Weather Station (Dct 9, 12 WSq) considered a forecast of 75-knot peak wind gusts sufficient for an early season hurricane moving at 10 knots northward into the cooler waters of the northern Gulf of Mexico. Tailored weather service provided the Commander at Tyndall resulted in net savings of over $400,000 through timely, but not excessive, storm preparations.

Source: Air Weather Service Value Analysis

CS-8

Tornado False Alarm

An excellent example of the shortcomings of the AN/FPS-77 occurred at this unit in the Spring of 1979. Preceding a frontal passage, a very active squall line formed west of the station. Several severe echoes were observed and a number of funnel cloud/tornadoes were reported in association with this system. Unit forecasters were faced with the usual dilemma of whether or not to issue a tornado warning based on radar representation that didn't clearly indicate such an occurrence as probable at the station. Issuance of a tornado warning for the Ft. Benning installation causes a severe disruption in all activities. School classes are suspended, training is halted, and all activities are disrupted. False alarms, obviously, do not meet with high favor. While the radar scope representation indicated severe thunderstorms would hit Ft. Benning, there was little indication of tornado activity. However, the issuance of a warning by the local NWS office, coupled with the sighting of a funnel cloud 15nm to the northwest decided the question, and a warning for tornadoes was issued. The warning did not verify. The loss to the post in terms of training and disruption of services was considerable. A radar capability that would more clearly define severe parameters would not only provide a better warning capability for actual occurrences but reduce costly false alarms such as we experienced.

Source: Det 10, 5WS, AWS letter dtd 9 September 80

CS-9

Thunderstorms/Lightning Advisories,
Langley AFB, Virginia

1. We have the following comments on the NEXRAD. The NEXRAD:

a. Must distinguish echoes within three nautical miles of a station. The ITFW would like us to issue met watch advisories when lightning is within three nautical miles of the Langley AFB tower. When an advisory is issued, all refueling and munitions loading activities cease. To support this requirement, we issue advisories for lightning within five nautical miles. We use five miles because the AFCC weather maintainance personnel have blanked out any echoes within five nautical miles on the 30 nm PPI scope. With ground clutter, it is very difficult to locate echoes within five nautical miles on the AR and RHI scopes.

b. Must pickup echoes with low tops at distances greater than 100nm from the station. The following example illustrates the problem. A line was moving at 50 plus knots. Due to the low tops, we did not pick up the echoes on the radar until the line was within 100nm of the station. We estimated the speed using less than one hour continuity. With our slower than actual estimate of line movement speed, we had a weather warning with a -12 minute timing error.

c. Must quickly determine echo movement. Example: An area of isolated thunderstorms built around the station. Other priorities (warnings, met watch, etc..) didn't allow time to establish good continuity from radar observations. After the thundershower began at the station, we were unable to give a good estimate of the ending time because the speed of the system was unknown. Another example. Nocturnal thunderstorms formed near sunrise. Due to their proximity, we needed to issue a warning ASAP. Our guess at the speed was too fast and the thunderstorms dissipated before reaching the station. The next morning thunderstorms formed again. We delayed putting out the warning until movement could be established. The result - insufficient lead time.

Extracted from: Det. 7, 3 AWS letter 16 Sept 80

CS-10

Severe Weather Warning Support at Vance AFB, Oklahoma

Background

1. Situation: Vance AFB is a UPT base located in a region with a high threat from severe thunderstorms and tornadoes. Pilot training operations are particularly sensitive to severe weather and T-38 aircraft assigned to the base are especially vulnerable to severe damage from hail.

2. Support Provided: Advance warning of the occurrence of high winds and/or hail on the base.

3. Decisions Improved:

a. Recall and recovery of base aircraft.

b. Installing hail covers or hangaring T-38 aircraft.

c. Securing loose objects on base, particularly on the flight line.

d. Personnel taking shelter when tornadoes are in the vicinity.

Value Analysis

1. Cost of Weather Support:

a. Direct: Investment cost of FPS-77 radar is $40,000.

b. Indirect: Severe weather warnings are only one service produced at no extra cost by the base weather detachment and AFGWC. The typical ATC weather detachment has a total recurring cost of about $250,000. Severe weather warnings for North America are handled by 13 persons at AFGWC.

2. Estimated Benefits:

a. Typical case:

(1) Improvement in productivity:

(a) Increase of 5% or more in the availability of T-38 aircraft due to reduction in damage rate. This corresponds to a program cost of $2 million per year.

(2) Reduction in costs:

(a) Reduction in damage, mainly to aircraft, of $150,000 or more per year.

(b) Elimination of several aircraft incidents each year by allowing more time for the orderly recovery of up to 100 aircraft normally flying in the area. No statistics are available to estimate the accident rate without adequate weather warning.

(c) Elimination of several personal injuries.

b. Extreme case:

(a) Essential elimination of the probability of extreme damage. Without sufficient warning of the arrival of storms, such as have occurred in the area in the past two years, the storms would have destroyed aircraft valued at $49 million.

(b) Substantial reduction in probability of tornado fatalities. No statistics are available to compare fatality rates with and without warnings such as are provided at Vance.

Source: Air Weather Service Value Analysis

CS-11

Weather Warning Service to Andrews AFB

Background

1. Situation: Andrews AFB, Maryland, like many other military installations in the northern two-thirds of the U.S., is subject to occasinal snow fall during the winter months. The 1st Composite Wing at Andrews has a snow removal plan which provides for a task force of fifty personnel to assemble at a central point two hours before the snow is forecast to begin. The minimum cost for assembly of this force is estimated at $500 per hour by the local civil engineer. As of 15 March 1973, only a few light snow showers had fallen at Andrews. Thus, for the first time on record, this late in the season, snow removal efforts were not required by the base.

2. Support Provided: The Andrews base weather station (BWS) provides routine forecasts and severe weather forecasts (to include snow alerts) for Andrews AFB.

3. Decisions Improved: Assuming the BWS did not exist, Andrews would have had to rely on forecasts issued by the National Weather Service. During the 72-73 winter season the NWS issued five snow forecasts for the Washington DC area. Without a local forecast service to refine these general forecasts the 1st Composite wing would have had to respond to each, thus spending $500 per hour needlessly until the warning was cancelled. Because the BWS did in fact refine the area forecasts, the snow removal teams did not have to assemble and were placed on telephone standby on only two occasions.

Value Analysis:

1. Cost of weather support: Negligible. The provision of local forecasts and point warnings is a routine function of the BWS. No manpower or resources are authorized solely to perform this function.

2. Savings realized: $15,000. It is estimated that without the BWS refinement, reliance on the NWS general area forecasts would have caused snow removal teams to assemble on five separate occasions for a minimum of six hours each.

6 hrs X 5 occasions X $500 per hour = $15,000.

Conclusions: Although the sum saved in this instance is small, the purpose of including it in the Value Analysis Program is to give an illustration of how one relatively minor support function provided by a base weather station can save the Air Force a substantial sum of money. Assuming the same general figure applies on the average to other Air Force installations with snow removal problems, the potential savings is on the order of $3/4 million (50 Air Force bases are subject to significant snowfall).

Source: Air Weather Service Weather Value Analysis

CS-12

Thunderstorm Watch Support to 20th Surveillance Squadron (ADC), Eglin AFB Florida

Background:

1. Situation: The 20th Surveillance Squadron (20SS) operates the FPS-85 phased array radar and its associated systems which are part of ADC's Space Detection and Tracking System (SPADATS). This multi-million dollar facility is located twenty miles east-northeast of Eglin's main base and receives its electrical power supply from a commercial supplier. The supplier employs a network of transmission lines over a 5,000 square mile area in southern Alabama and Georgia. These lines are susceptible to lightning strikes which cause power fluctuations at the 20SS. These fluctuations in turn may cause data losses or damage and excessive downtime in the SPADATS circuitry. Provision was made for back-up power in the form of gas turbine-powered generators, which are also owned by the power company. The generators are turned on whenever requested by the 20SS. This action isolates the SPADATS from the main power line.

In February 1971, an uninterruptable power system (UPS) was installed which protects portions of the SPADATS (i.e., computers and communications center) from power surges. However, when the UPS is inoperable (over eight months in 1972) and there is a threat of lightning, the 20SS must activate the back-up power to protect communications and computer gear.

2. Support Provided: Detachment 10, 6 WWg, issues special met watch advisories which warn of possible lightning occurrences throughout the 5,000 square mile area. Special emphasis was placed on this tailored support following a working agreement between the 20SS and Det 10, 6 WWg personnel in February 1971. Special maps and radar grid overlays are used to identify the areas in which the collection net and power lines are located.

3. Decision Analysis: The tailored support provided by Det 10, 6 WWg directly assists the operator in determining if backup power will be needed. This decision assistance has significantly reduced the amount of back-up power needed by the 20SS. The impact of this assistance can be demonstrated in the table below which outlines the cost of backup power to the 20SS over the last four years.

(1) FY 70 - $357,765.00
(2) FY 71 - 297,450.00
(3) FY 72 - 11,812.00
(4) FY 73 - 59,287.50

Value Analysis

1. Cost of weather support: an average of 30 manhours per month are expended by Det 10 personnel to provide weather warning service to the 20SS. Using cost figures obtained from AFM 173-10 and the Dep 10, 6 WWg UDL, the average cost per manhour of Det 10 support was estimated at $6.28.

$$\text{Total cost is } 30\ \frac{\text{hours}}{\text{month}} \times 12 \text{ months} \times \frac{\$6.28}{\text{hour}} = \$2,260.28$$

2. Estimated benefits: The cost reduction of $60,315 in backup power operating costs between 1970 and 1971 has been attributed to the decision assistance provided by Det 10, 6 WWg. The annual recurring value of this support since 1971 is estimated by the 20th SS to be in this same range.

3. Net savings:

a. Cost of weather service: $2,260.28.

b. Reduction in operator costs, FY 70-71: $60,315

c. Net annual savings incurred by operator due to weather support: $58,054.72.

Source: Air Weather Service Value Analysis

CS-13

Launch Pad Lightning Warning System

BACKGROUND:

1. Situation:

a. The Air Force Eastern Test Range (AFETR) is both vulnerable and sensitive to the occurrence of lightning. The potential operational hazards from lightning strikes at the Air Force Eastern Test Range (AFETR) are considerably greater than that experienced at most Air Force installations. This results from the large numbers of separate complexes and vertical extent of vehicles and gantries. The possibility of damage or injury during fueling and other operations is a continuing threat.

b. Detachment 11/6WW formerly provided advisories of possible lightning discharge but limited to only the information gained from tracking thunderstorms by radar. This method did not allow for a precise prediction of the location of lightning activity. Under this concept, an advisory was issued for the entire Cape area any time a radar-tracked storm approached within five miles of the Cape in order to ensure personnel and equipment safety. Upon issuance of the advisory, all lightning sensitive operations were stopped and personnel in exposed positions throughout the Cape area were evacuated to safer locations. Such procedures cost various project offices in terms of idle man-hours. For examplee in 1970 the DELTA program estimated a loss of at least $10,000 from work halts as a result of the threat of lightning. Similarly, TITAN III and the Navy estimated losses due to work stoppage of $15,000 and $10,000 during the same period.

2. Support Provided: In order to decrease work stoppage resulting from overprotection due to false alarms at Cape Kennedy, Detachment 11 developed a lightning warning system incorporating two A.D. Little flash counters, eight field mill sensors, and a data acquisition system. The system alerts the duty forecaster whenever lightning charges occur within a radius of 40 miles and allows him to monitor the electrostatic field potential and lightning phenomena from eight key operational locations throughout the Cape. The sensor data are collected by the data acquisition system and the analog signals from the field mills are also recorded on Esterline Angus chart recorders. This, coupled with radar information, enables the forecaster to pinpoint the location and intensity of existing and potential electrical storms and allows him to tailor and issue lightning advisories for individual launch pads.

3. Decisions Improved:

a. AFETR program managers are able to safely continue normal operations even though thunderstorms are occuring in the area. Shutdowns are required only when the complex in question is threatened. This has substantially reduced the operational downtime previously experienced as a result of potential lightning hazards.

b. Detachment 11 now possesses the intelligence to recommend a launch delay when a particular launch complex is under the influence of lightning producing clouds.

VALUE ANALYSIS:

1. Cost of Launch Pad Lightning Warning System:

a. Initial investment:

(1) Detachment 11 staffmet support in planning, developing and acquiring the system.

$\frac{\text{358 man-hours}}{\text{1728 man-hours available/yr}}$ X \$41,650/staffmet/yr=\$ 8,629

(2) Equipment costs \$ 20,000

Investment costs \$ 28,629

b. Recurring Costs:

(1) Detachment 11 forecaster support in monitoring the equipment and issuing additional advisories (includes 280 man-hours/yr) at \$8.21 per hour--\$8.21 X 280 = \$ 2,298/yr

(2) Maintenance Cost (AFETR/PAA contract) \$ 6,000/yr

Total Recurring Costs \$ 8,298.80

c. Total annual cost of system:

(1) Yearly initial investment costs amortized over estimated eight year life of the system: \$ 5,115.04

(2) Annual operating & Maintenance Costs \$ 13,413.84

2. Estimated Benefits:

a. Direct: In order to determine benefits, the lightning advisory output for the Cape during June through October 1974 was used. This period represents the peak thunderstorm season. During this period, some portion of the Cape was subject to lightning activity -- a total of 555 hours. With the LPLWS, advisories were only in effect for any particular launch complex an average of 113 hours. In the past, advisories would have been issued for the Cape and Navy Port for the entire 555 hours. Thus, work stoppages are potentially reduced by ($100\% - \frac{113}{555} \times 100\% =$) 79.6%.

b. In order to establish the meaning of reduced work stoppage, data for the June-October 1970 time period were examined. These were the only comprehensive data available. For example, the DELTA, TITAN III and Navy programs recorded a composite loss of $35K due to work stoppage based upon electrical storm advisories. Based upon paragraph "a" above, 79.6% of this overprotection could have been avoided had the LPLWS been in use. Thus, .796 X $35K = $27,860 potential savings for the 1970 period. Using the total $13,413 and adjusting this to FY 1971 dollars ($13,413/1.398 = $9.594), the FY 1971 benefits are computed.

c. Benefit/cost ratio (FY 1971):

$$\frac{\$27,860}{\$\ 9,594} = 3:1$$

Source: Air Weather Service Value Analyses

Value of Severe Weather Service at Laughlin AFB, Texas

BACKGROUND:

1. Situation: Laughlin AFT, Texas, is an Air Training Command (ATC) base engaged in the undergraduate pilot training (UPT) program. This mission is performed by the 47th Flying Training Wing (FTW), the host base unit. The principal severe weather problems impacting the mission at Laughlin AFB are lightning, hail (over 1/2"), winds over 35 knots, and tornadoes. The 47th FTW uses both T-37 and T-38 aircraft to accomplish the training mission. The T-38 is particularly susceptible to the damaging effects of hail.

2. Support Provided:

a. During normal duty hours, severe weather warnings for Laughlin AFB are provided by the base weather station forecaster.

b. During hours when a forecaster is not on duty in the base weather station, severe weather warnings for Laughlin AFB are provided by the Air Force Global Weather Control (AFGWC), Offutt AFB, and relayed through the ATC Command Post, Randolph AFB.

c. Larger scale area advisories of severe weather are provided at all times by the AFGWC.

3. Decisions Improved:

a. Recalling and recovering of aircraft.

b. Securing aircraft through hangaring, tie-down, and covering of appropriate aircraft surfaces.

c. Scheduling of computer operations.

d. Scheduling of refueling operations.

VALUE ANALYSIS:

1. Cost of Weather Support:

a. Annual costs of weather detachment	$290,000
b. Cost of operational actions dictated by forecasts which did not verify	62,800
	$352,800

2. Estimated Benefits:

a. Direct:

(1) Costs incurred if warnings were disregarded (i.e., no preventative action taken by host command). $259,100

(2) Increased base productivity derived through the actions of the BWS forecaster to downgrade warnings issued by the AFGWS for Laughlin AFB. $420,000

$679,100

b. Indirect: Possible loss of 40% of the T-38 fleet due to severe weather damage.

Pro-rated annual cost $920,000

3. Net annual savings:

a. Direct: $679,100 - $352,800 = $326,300

b. Direct and Indirect:

$679,100 + 920,000 - $352,800 = $1,246,300

4. Conclusions: The base weather station at Laughlin AFB contributes significantly to the effectiveness of the pilot training program conducted by the 47th FTW. This enhanced effectiveness is primarily derived through advanced notification of severe weather events which contributes both monetary savings and increases the efficiency of the overall pilot training program.

Source: Air Weather Service Value Analysis

CS-15

Tornado Activity, Bergstrom Air Force Base, Texas

1. While there are, without doubt, numerous instances where a Doppler Radar may have proven beneficial and/or provided more accurate warnings to our customers, a specific example would be hard to substantiate. There are several cases in our experience where a Doppler system would have probably indicated the presence of severe weather when our FPS-77 didn't. A brief description follows:

a. A spiral band associated with Hurricane Allen spawned numerous small tornadoes and did considerable damage in the Austin area. The Bergstrom AFT FPS-77 radar, although functioning according to specification, did not adequately portray this tornadic activity. This apparently was mostly due to the PPI characteristics of the FPS-77 as the nearby NWS WSR-74 (non-coherent 5 cm radar) clearly depicted (as small hook echoes) this event.

b. In many instances, false alarm weather warnings for gusty winds have been issued based on measured reflectivity, reflectivity gradient, and/or radar detected cloud tops. A Doppler system would have probably reduced the number of these false alarms.

2. In our experience, the FPS-77 is adequate at identifying hail-producing thunderstorms from those that do not produce hail and also quite good at detecting very severe echoes and organized convection systems. The principal operational utility of the proposed Doppler system is its well-documennted capability to detect strong winds.

Extracted from 25th Weather Squadron, AWS letter, 22 October 1980

CS-16

Future Disaster: Miami

From: Hurricane Hazard in the United States: A Research Assessment; by Waltraud A.R. Brinkman; Rann Document Center, National Science Foundation

The threat posed by hurricanes at many points along the South Atlantic and Gulf coasts is dramatized by an account of vulnerable population and property in dynamic interaction in Maimi, Forida. The following is a current judgement of the probable results of a hurricane of a given strength striking a sector of the Florida shore where the parameters of occupance and adjustment are known. It concentrates on threats to life and does not estimate total property losses.

The meteorological catalyst is a large, slow-moving, wet hurricane making landfall south of Miami. Specifically, it is a hurricane with a central pressure of 925 mbs and radius of maximum winds of 15 miles. This is equivalent to Donna (1960), Carla (1961), and Betsy (1965), and much less severe than the Keys storm of 1935, which drowned 730 people in that relatively low density population area. It passes just south of Key Biscayne and moves onshore at 15 mph at the new residential community of Saga Bay (see Figure VI-1).

Under these conditions, the National Hurricane Center in Coral Gables issues a warning for residents of Key Biscayne, Virginia Key, and south Miami to evacuate. Such a warning is normally made with at least 12 hours of daylight remaining before the predicted landfall of the hurricane.

Key Biscayne and Virginia Key are about five miles off the coast of south Miami. Virginia Key is occupied by a sea aquarium, the oceanographic laboratories of the University of Miami, and research facilities of the National Oceanic and Atmospheric Administration. Key Biscayne, a large residential community of mostly wealthy residents, is attractive for residential location due to the close proximity of the water and its distance from the more congested mainland. The elevations of these areas above mean sea level range from two or three feet to about ten feet, with an average of approximately five feet. Rickenbacker Causeway, a two-mile bridge across Biscayne Bay bisected by a drawbridge, connects Key Biscayne and Virginia Key with the mainland. At best, it requires at least nine to ten hours to evacuate the approximately 10,000 inhabitants.

A number of possible events could preclude successful evacuation of the entire population. First, not all of the 12 hours of warning are available for evacuation. As much as six hours prior to a slow-moving hurricane's landfall, storm surge may cause tides to begin rising, thereby flooding some low points on roadways used for evacuation, and bringing automobile traffic to a halt. Even before the storm surge hits its peak at the coast, traffic is snarled by a combination of congestion, weather, flat tires, and automobile accidents. Residents of Key Biscayne and Virginia Key must act swiftly to evacuate once the warning is received in order to avert a major disaster; those not promptly heeding the warning are trapped by the time the magnitude of the hurricane becomes visibly apparent. Since a large proportion of Florida's population has never witnessed a severe hurricane, a warning response rate of less than 50% can be expected.

The drawbridge represents another weak link in the escape route. With the onset of a major storm, marine traffic through the drawbridge increases as vessels seek the shelter of the Miami River and other havens northward. Commercial marine traffic is normally heavy, and several times in past years, barges (which are now pushed rather than pulled by tugboats) have jack-knifed while passing through the raised bridge and jammed its mechanisms. Rising winds and heavy seas contribute to the probability of such an event. Even without such an accident, drawbridges periodically fail and lock in the up position.

Severing the causeway for any reason means large fatalities from storm surge in the trapped population. Alternative escape routes are severly limited by time and geography. No large boat landings exist on either Key Biscayne or Virginia Key, so only small craft can be utililzed for an evacuation by sea. Only a handful of people can be transported at a time, and organizing and carrying out such an operation consumes much precious time. Moreover, the danger to those in boats increases rapidly as the hurricane approaches.

Evacuation by air is precluded by the lack of an airport and the danger of utilizing helicopters in high winds. Vertical evacuation into high-rise condominiums is an increasing possibility with new construction, but is limited by space and the willingness of owners to allow public access to their private property. (The problem is analogous to that for private atomic bomb shelters during the 1950's.) The five- to ten-foot land elevations afford minimal shelter from the wind-driven storm surge waves of 10-15 feet along the right side of the hurricane.

Mainlanders also experience severe difficulties in their attempts to evacuate. A storm surge six hours in advance of the hurricane's center catches many residents still preparing to leave. Heavy rainfall and high winds also hamper evacuation attempts.

Saga Bay is an excellent example of how the hurricane disaster potential is exacerbated by coastal development. The area is located south of Miami in the area below Old Cutler Road and above Black Point; it is anticipated to house a population of approximately 100,000 to 150,000 initially. Feasibility of the development was enhanced by construction of the West Dade

Expressway, which is connected to Saga Bay by the Old Cutler Road. Elevation of the Saga Bay area varies from sea level to five feet above mean sea level.

In order to meet Federal housing regulations, houses are elevated five feet above mean sea level on fill dug from nearby man-made lakes. The Saga bay developers, however, also tore out the mangroves along the coast, which are unsightly and ill-smelling. These mangroves formerly provided one of the few effective barriers to storm surge, and the smooth, cleared beaches that are being built invite the unrestrained sweep of storm surge across the entire area. Storm surge accompanying a hurricane of magnitude postulated cannot be deterred by the slight elevation of the houses.

The evacuation route for Sage Bay residents is along Old Cutler Road to the expressway and then north. While Old Cutler Road generally has an elevation of five to ten feet above sea level, and might not initially be affected by storm surge, heavy rainfall swells Black Creek beyond its banks and cuts the shortest route to the expressway.

Travel north on Old Cutler Road carries evacuees to the already overburdened and inadequate Dixie Highway, and into the congestion of evacuees from Key Biscayne, Virginia Key, and Coral Gables at the intersection of the Rickenbacker Causeway, Dixie Highway, and Interstate Highway 95. Regardless of the direction of travel on Old Cutler Road, evacuees from Saga Bay encounter serious congestion and slow-moving traffic as the capacity of the road is exceeded and the weather deteriorates. Time runs out for many as they find themselves trapped in their automobiles when the hurricane hits.

Reaching the West Dade Expressway does not mean safety, however, and further obstacles must be overcome. The expressway connects with the Florida Turnpike, which is located west of most residential development in the Miami area. It too becomes severly overburdened as Miami residents evacuate. The Palmetto and the North-South (I-95) Expressways have major tie-ups, as do all northbound streets, and travel is induced westward to the turnpike extension.

The severity of traffic jams in Miami is made worse by the interaction with two evacuation operations, those for boats, and those for people by automobile. Slip lease agreements between boat owners and the marinas normally stipulate that owners will evacuate their boats when a hurricane warning is received. At the time of evacuation, these boats are instructed to proceed to the mouth of the Miami River to be escorted up the river in flotillas. Other than the expressways, all of the major north-south arteries in Miami cross the Miami River and, therefore, have drawbridges. The use of flotillas is designed to minimize the raising of bridges, but major automobile tie-ups occur; once the flow of traffic is interrupted it takes considerable time to return to normal.

In addition, the evacuation of boats poses a serious threat of a catastrophe at sea. There are roughly 10,000 small craft registered in Biscayne Bay, but only 1,000 of them can be accommodated up the Miami River. When the river is full, boats are turned away to seek another refuge. No other shelter is close at hand, however, and many boats are caught in open water by the hurricane.

Flooding hampers evacuation operations, as well as severly damaging property. Much flooding is caused by the South Florida Water Control Conservation Project, which is a large network of canals constructed by the Corps of Engineers to prevent flooding of agricultural land in south central Florida. These canals flow to the sea through most residential communities in Dade and Broward Counties and, in fact, provide high-priced, waterfront sites. With the onset of storm surge, however, their flow to the sea will be blocked and with heavy rainfall they can be expected to flood both streets and property.

In sum, the total loss of life is high. A storm surge well in advance of the hurricane's center catches many still preparing to evacuate. Flooding of escape routes due to heavy rain exacerbates the severe traffic tie-ups which are normally expected with a large number of automobiles. (Rush hour traffic probably represents less than 25% of the traffic which could be expected with a warning to evacuate, and even this amount cannot be accommodated without major delays.) Warning and evacuation as they now are planned and proceed are inadequate responses to the posted threat.

CS-17

From: Destructive Winds Caused by an Orographically Induced Mesoscale Cyclone

By: Richard J. Reed, Department of Atmospheric Sciences, University of Washington, Seattle, Wash., American Meteorological Society, 1980.

The Hood Canal Bridge was a floating structure of 1 1/3 mile length spanning the Hood Canal, a deep, narrow, 50 mile long natural body of water that forms the westernmost arm of the Puget Sound system of inland waterways. The location of the bridge, near the mouth of the canal, and the locations of other geographical and topographical features of interest here are shown in Figure 1. Of particular significance to the present investigation are the Olympic Mountains, which rise abruptly to average heights of 5000 feet or more within a distance of less than 20 miles from the bridge, and the Cascade Range, which constitutes a higher and more extensive barrier 50 miles to the east.

The bridge floated on 25 pontoons anchored by steel cables to the bottom of the canal in depths up to 340 feet. The middle pontoons were moveable and could be retracted into bays to form a 600 foot opening for the passage of large ships. As a safety measure for reducing wave forces, the moveable pontoons could also be retracted, and the bridge closed to traffic, when winds exceeded 50 mph. First opened to traffic on 12 August 1961, the bridge was constructed over a period of nearly three years at a cost of 27 million dollars. Its replacement cost today is estimated to exceed 200 million dollars.

At 2330 PST on the night of 12 February 1979 an alarm sounded in the toll collectors' booth at the east end of the bridge, signalling that winds at the control tower, located just west of the moveable section, had reached a speed of 45 mph. According to standard operating procedures, the bridge tenders were notified to report to duty in case the winds rose beyond the 50 mph mark and the center section required opening. After hovering near the 45 mph figure for a period of nearly 2 hours, the winds resumed their upward climb and at 0130 PST on the 13 passed the 50 mph threshold, requiring the bridge to be closed to traffic. It was reopened briefly a short time later to allow repair crews to cross to the west side, where power lines already were being knocked down by falling trees. It was then closed for what proved to be the final time.

As the night progressed the winds continued to increase. By 0500 PST sustained speeds at the control tower were approaching 80 mph and, for the first time in the history of the bridge, gusts reached the 100 mph mark, the highest value appearing on the strip chart. At 0600 PST the bridge crew noticed that the control tower was beginning to lean to the south. About 1/2 an hour later, as the first light of dawn appeared, they observed that the roadway to the west was undulating and that one of the pontoons was also listing to the south. At 0640 PST the decision was made to vacate the bridge. As the tenders drove off in their pickup truck, they tried to persuade a trucker, who had driven his semitrailer on to the west section, to leave with them. But at great risk to his safety the latter remained with his truck, slowly backing it off the narrow roadway. At approximately 0700 PST he managed to bring the vehicle on to the fixed pier that joined the bridge to land. Almost immediately the east end of the transition span collapsed and pivoted into the water. By 0800 PST the entire 3200 foot west section of the bridge had gone under. The east section remained intact.

Following the bridge collapse, the Washington State Department of Transportation employed a consultitng firm, Tokola Offshore, Inc., of Portland, Oregon, to determine the cause of failure. The author was retained by the firm to assist with the meteorological part of the investigation. Specifically, the meteorologist's tasks were to determine: 1) the wind conditions that existed in the vicinity of the bridge at the time of failure; 2) the cause of the extreme velocities that were reported to have occurred; and 3) the likely return periods for various specified extreme velocities at the bridge location. Only the first and second of these objectives will be treated in the present article.

Since wind equipment was mounted on the bridge, it might seem at first sight that the task of establishing wind conditions in its vicinity was a trivial one. However, the wind equipment and recording apparatus were lost when the bridge went down. The foregoing account of the wind behavior was based on the bridge tenders' recollections of events, not on recorded data. In view of the harassing conditions under which they operated and the extraordinary nature of the winds they reported, further substantiation was clearly required. Moreover it was not sufficient to know only the velocities at the bridge. To determine the major force acting on the bridge - that produced by wave action - it was necessary to know the fetch of the wind and the speed along the fetch. Thus, an estimate of the wind direction and speed was required for the length of lower Hood Canal.

In this paper it will be shown how it was possible, with the help of nonroutine data, to reconstruct the likely wind behavior in lower Hood Canal on the morning of the catastrophe. The analysis not only supports the extreme velocities recalled by the bridge tenders but reveals the existence of an hitherto unsuspected, or only partly suspected, mesoscale phenomenon that contributed importantly to the severity of the winds.

CS-18

TORNADO WARNING AT ALGONA, IOWA, June 28, 1979

Gary St. Clair, Manager of Hy-Vee Grocery in Algona, Iowa, described his experience during the June 28, 1979 tornado that all but wiped out a large portion of Algona. (See attached page from "Storm Data" plus Map of Tornado paths). Gary indicated that 30 minutes advanced warning is "priceless". The Algona tornado was worst disaster in buildings and homes in Iowa records. He worked an ambulance crew in clean up. In this case, there was no NWS warning. The tornado was spotted by some people who were on a hilltop overlooking the town and spotted the funnel cloud to the north approaching Algona. They radioed using C/B channel 9 to local police (police monitor CB9) that spotted funnel was heading for Algona - Sirens sounded -. With this 15 to 20 minutes before it struck notice, everyone knew to get into their basements, to break up baseball games, and to alert people in shopping malls (his store is only one with a basement) to evacuate people in the mall to the basement of Hy-Vee. Result - all people but 2 in town saved. These 2 were elderly people who could not get to shelter but were found dead in their homes which were airborne for some distance. He also mentioned Algona's attempts to insure that deaf people were aware of watch/warnings. He related his feelings during the rescue after the storm (stopped his store clock at 7:13 LDT on the 28th of June) of seeing just bare land - no buildings, no crops visible. He wished us to speed up this new detection system and said 1985 was too late. How will you explain the delays to those killed between 1981 and 1985 (or whenever NEXRAD is operational). He said that with a well-understood plan to avert disaster as exists in Algona - a 15-20 minute warning will be priceless in value in saving lives. In brief, with 15-20 minutes of warning all but 2 people out of a thousand or more in its path were saved.

Source: Sonicraft File

STORM DATA AND UNUSUAL WEATHER PHENOMENA

Place	Date	Time - Local Standard	Length of Path (Miles)	Width of Path (Yards)	No. of Persons Killed	No. of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
IOWA									
[illegible]									
3 SW Bancroft to Algona to 1 NE Irvington Kossuth County									Tornado

3 SW Bancroft to Algona to 1 NE Irvington Kossuth County	A large tornado touched down 13 miles north of Algona and moved south-southeast. The tornado stayed on the ground tearing up crops and damaging numerous farms before slamming into Algona. The tornado destroyed 104 homes and 20 businesses. Numerous trees and cars were also destroyed. 349 homes were damaged. After smashing through Algona the tornado moved south-southeast for 3 miles and then began to narrow and took a turn to the east-southeast before dissipating.

Place	Date	Time	Length of Path (Miles)	Width of Path (Yards)	Killed	Injured	Property	Crops	Character of Storm
3 S Terril Clay County	19	6:00P			0	0	0	0	Funnel Cloud
1 NE Creston Union County	19	6:30 P			0	0	0	0	Funnel Cloud
2 NW Preston Winnebago County	19	5:30 P	.2	30	0	0	4	0	Tornado
3 N. Bloomfield Davis County	20	1230A	.4	30	0	0	4	0	Tornado
North Central and Central	20	3:00P-12:00P							Severe Thunderstorms
1 E Armstrong Emmet County	20	3:12 P	.5	30	0	0	0	3	Tornado

Place	Date	Time	Property	Character of Storm
Breckinridge Cy	6	[illegible]	4	Svr Tstm
Caldwell Cy	7	[illegible]	4	Svr Tstm
Mason Cy	7	[illegible]	4	Svr Tstm
Adair Cy	8	[illegible]	4	Svr Tstm
Hancock Cy	7	[illegible]	4	Svr Tstm
Ballard and McCracken Cys	20	[illegible]	4	Svr Tstm
Marshall Cy	20	[illegible]	3	Svr Tstm

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TORNADO PATHS – JUNE 28, 1979

TIME: LOCAL STD.
SOURCE: NOAA STORM DATA, 1979

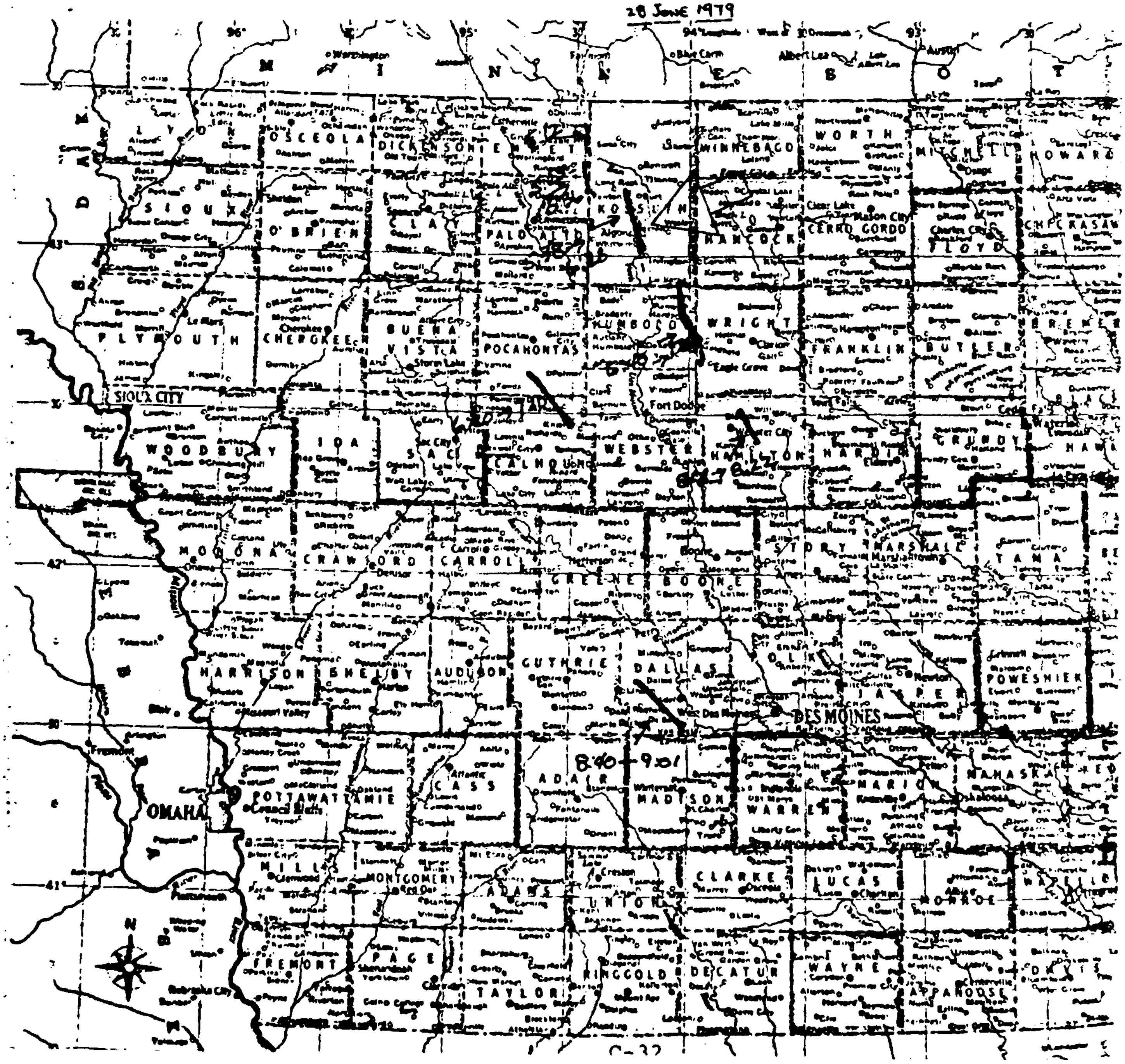
Iowa

COUNTIES

CITIES AND TOWNS

[illegible]

28 JUNE 1979



APPENDIX D

NEXRAD PERFORMANCE ESTIMATES

This appendix contains:

1. A copy of a letter asking for estimates of performance of three proposed NEXRAD radar designs compared to today's WSR-57; including two enclosures to the letter - the characteristics of the four radars to be compared and a matrix listing the radars and nine hazardous weather phenomena.

2. A list of the individuals who contributed to this study by responding to the letter - each in his own fashion. We received 21 responses, 14 of which contained data used in completing the matrix.

3. Summary of the data collated to show in graphical form: (1) the estimates of difference in performance between the Doppler (Radar Types II and III) and the non-Doppler radar for each of the phenomena; (2) estimates of the performance percentage improvement (or non-improvement) of each radar type by each phenomena.

4. Extracts from each response where the comment pertained to a particular phenomena - collated by phenomena.

Dear :

The Federal government has begun a joint program to replace the existing national weather radar network with a next generation weather radar (NEXRAD). The new network is planned to be operational in the late 1980's, At present NEXRAD is more than a concept but somewhat less than a firm design. One of the initial steps is to make a preliminary cost/benefit assessment of the proposal. As you probably know, experimental data to quantitatively determine the economic value of weather radar observations are not readily available from published reports. Neither have the benefits of Doppler weather radar in a real-time environment been determined for many of the severe weather phenomena of interest in this study.

As a recognized authority in weather radar and in its application to severe storm phenomena detection, location and tracking, we are confident that you share our interest in the Next Generation Weather Radar System. Your considered response will be extremely helpful to all in the weather radar community. We, therefore, solicit your judgment of the improvements resulting from the proposed NEXRAD designs -- even at this early stage of development. We are asking that you read the enclosed material and provide your assessment of the degree of improvement resulting to the radar performance. A listing of the performance characteristics of the proposed radars is enclosed along with information extracted from draft reports on the NEXRAD system. We solicit your rough but considered judgements, a "first" impression or approximate extimate rather than a detailed analysis. If you were to choose a range of percentage values of improvement, what range would you pick?

To aid in this assessment, we have put together a structured format, copy enclosed, which proposes that a percentage change in radar performance be judged for the NEXRAD performance over the current radar system for each one of the nine hazardous weather phenomena being analyzed.

Such a set of "what if" questions carries with it many built-in assumptions. Recognizing this, please feel free to make any notations regarding an important factor that should be carefully considered in judging the performance. This Delphi type technique in postulating the improvements in the weather radar performance should contribute significantly to filling in any gaps in this benefit assessment.

The Federal Aviation Administration as part of its support to the joint NEXRAD program office has contracted with Sonicraft, Inc. to prepare a "Preliminary Cost Benefit Assessment of Systems for Detection of Hazardous Weather". I have asked Mr. Edmund Bromley of Sonicraft (202-554-3002) to contact you by phone in a few days to see if you have any questions and to solicit your responses.

As you may have surmised, we are not providing any remuneration for your estimates but do believe your judgments can contribute to this early-on analysis. We expect to reference the results of this survey in the final report without identifying the individual contributions.

We have asked this favor of many of your colleaques enumerated on the attached distribution list.

Kenneth Kraus
Planning Analyst
Office of Aviation System Plans
(202) 426-3338

Enclosures:

1. Wx Radar Performance Characteristics
2. Suggested Format for Estimate
3. Selected Extracts re. NEXRAD
4. Distribution List

Enclosure 1

WEATHER RADAR PERFORMANCE CHARACTERISTICS

		NEXRAD TYPE		
CHARACTERISTICS	WSR-57	TYPE II DOPPLER	TYPE III DOPPLER	TYPE IV NON-DOPPLER
Range	250 nmi.	250 km	250 km	250 km
Pulse Width (km)	.15 km	0.6 km	0.6 km	0.6 km
Maximum Elevation	45	20	20	20
Altitude	70000 ft.	70000 ft.	50000 ft.	70000 ft.
NR Beams, Beam Width	1/2.2°	2/1°	1/1°	1/1°
PRF	658/164pps	1000/300pps	1000/300pps	300pps
Update Rate	Not Applicable	6.2 min.	11.7 min.	8.3 min.
Reflectivity/ Uncertainty	1dBz	1dBz	1dBz	1dBz
Rotation Rate	3 rpm	2.4 rpm	2.4 rpm	2.4 rpm
Velocity	--	1 m/sec	1 m/sec	--
Velocity Spread	--	1 m/sec	1 m/sec	--

WEATHER RADAR TYPES

PHENOMENA	TODAY'S RADAR WSR-57	NEXRAD TYPE II (PERCENTAGE IMPROVEMENT)	NEXRAD TYPE IV (PERCENTAGE IMPROVEMENT)	NEXRAD TYPE III (PERCENTAGE IMPROVEMENT)
TORNADO				
TURBULENCE				
THUNDERSTORM				
HAIL	BASE			
ICING				
FLASH FLOOD				
WIND				
HURRICANE				
SEVERE WINTER STORM				

LIST OF CONTRIBUTORS

Dr. Ron L. Alberty, PROFS Program, Environmental Research Laboratories

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Dr. Louis J. Battan, University of Arizona, The Institute of Atmospheric Physics

Mr. William Biqgers, Eastern Air Lines, Chief, Meteorology Department

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Dr. Gregory S. Forbes, Pennsylvania State University

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Dr. Frederick P. Ostby, Director, National Severe Storms Forecast Center, NOAA

Mr. Paul Rempfer, Transportation System Center, Department of Transportation

Dr. Robert J. Serafin, National Center for Atmospheric Research

Dr. Bernard A. Silverman, Office of Atmospheric Resources Management, Water and Power Resources Service

TORNADOES

Comment 1

Comments on important features for a radar to be used to identify and track severe weather phenomena.

Experiments have shown that great improvement is obtained with Doppler capability both in the definite detection of tornadoes and in the lead time between detection and damage at points on the surface. It is doubtful that digital processing without the Doppler capability would provide significant improvement, but high spatial resolution should be helpful in depicting tornado "hooks" and especially in extending the range to which they can be identified. Because of the very short time available for tornado warnings, any minutes gained through a rapid update rate are definitely advantageous.

Comment 2

We have found it extremely difficult to identify percentage improvements and have responded on your structured format in semi-quantitative terms. In addition we have specific comments on each of the phenomena below:

The increased ability to detect tornadoes with a Doppler radar Type II and III is very high. All Doppler types should be equally capable of the detection of tornadoes, but the faster the scanning mode the earlier (on the average) the identification can be made.

Comment 3

I associate tornadoes with the largest improvement attributable to Doppler capability. The 25 per cent improvement that a Typye II NEXRAD radar might bring compared with a Type III NEXRAD radar is attributable to receipt of immediate information on vertical continuity, provided by the 2-beam Type II radar. As an illustration of significant uncertainty please refer to the enclosed short paper suggesting avenues for use of radar data toward improvement of numerical weather forecasts. It is conceivable that developments in this area could lead to some improvements to winter storm forecasts of the 1990's with a raising of the guesstimates in the last row of the table.

Comment 4

I will not recount my liturgy of the fallacies of cost-benefit analyses, but simply note that I have not seen any in the meteorological field which will withstand scrutiny. Where catastrophic hazards are involved, how does one value life and limb? Singular events such as a major tornado or the crash of a loaded aircraft must dominate the decision-making process, and no cost can then be considered excessive.

TURBULENCE

Comment 1

Again the Doppler radar is a vast improvement over the WSR-57. All three Doppler types do an equal job in detection, particularly in non-thunderstorm turbulence. In cases where time is a factor, either from an operational viewpoint (e.g., airport surveillance) or by virtue of the generating meteorological phenomena (thunderstorms), the values of Type I or Type II are enhanced.

Comment 2

Although in theory a broad Doppler spectrum should represent a criterion for turbulent regions, actual measurements have not borne this out. Broad spectra can also result from noise, wind shear, and other factors. The ability of radar for direct detection of turbulent regions is thus very uncertain. It is my opinion, however, that within the next decade or so the information we obtain through expanded digital and Doppler measurements will lead to useful techniques for identifying turbulent regions within storms.

Comment 3

Table II uses a scoring system with a scale from 0 to 10; 10 is perfect and 0 represents *no capability*. Note that, for many purposes such as measurements of winds and turbulence, the non-coherent radars are given zero scores. This may be slightly unfair due to the fact that, with clever processing of the non-coherent signals, one can obtain structure function measurements and spectral width measurements with a non-coherent radar. These exceptions, however, would not change the overall results significantly.

Comment 4

I believe several important applications of Doppler radar technology should be added to any list of potential improvements in service to the public. Applications in optically clear air and more general application in widespread precipitation (such as boundary layer heights and Doppler velocities within that layer, as well as frontal location in very exact geometry) screams for attention by NEXRAD.

Comment 5

Doppler radar would be most useful, in my opinion, for detection of wind shears, gusts, and turbulent regions. I have included frontal and gust frontal windshifts in this category of turbulence. Doppler radar would also suggest areas of downdraft and updraft, and their strengths, which provide additional information on distinquishing severe from non-severe thunderstorms.

Comment 6

The aviation user desires information regarding the location and movement of hazardous weather including, heavy precipitation, hail, and severe turbulence. The WSR-57/EWEDS/RWRDS system will provide such information primarily using reflectivity at a single low elevation sample (with infrequent echo tops reports). The addition of automated elevation sampling will provide for superior information on the vertical nature of hazardous weather. There is strong evidence that this will permit improved hazardous weather algorithms regardinq both hail (e.g. reference Lemon, L.R., 1978: On the Use of Storm Structure for Hail Identification, 18th Conf. on Radar Meteor.) and turbulence (e.g., reference Crane, R.K., 1979: Automatic Cell Detection and Tracking, IEEE Transactions on Geoscience Electronics, Vol. GE-17, No. 4). These improvements should improve both safety of flight (presuming that their probability of detection will be better that those based upon one elevation sample) and reduce delays by freeing up airspace declared as hazardous by unnecessarily conservative algorithms.

The addition of Doppler variables further enhances the ability to characterize severe weather. There is evidence that not only does this improve our ability to infer turbulence but that the estimate of spectrum width is actually a detector of turbulence (reference Lee, J.T., 1977: Applications of Doppler Weather Radar to Turbulence Measurements which Affect Aircraft, FAA-RD-77-145) offering further refinement of turbulence avoidance algorithms.

THUNDERSTORMS

Comment 1

Although it does not specifically detect electrical activity, the WSR-57 does a fairly good job of identifying and tracking severe convective storms by recognizing intense reflectivity, rapid development and high cell tops. We would expect identification through such features to be improved by digital data processing, finer spatial resolution, rapid update rate and deep vertical coverage. Again the resolution is important in extending the range for recognition of small-scale features. With our present state of knowledge, the Doppler information would not be of any particular benefit. After a few more years of research, however, it may turn out to be very useful in predicting the storm's track.

Comment 2

This is a phenomenon of several hazards. Since tornadoes and hail are discussed elsewhere, it is sufficient to argue that Doppler radars should provide detection of thunderstorm outflow boundaries (see Wilson et al., 1980, BAMS). This should be of critical importance near airports. Moreover, thunderstorm development and changes can be extremely rapid, and frequently on relatively small scale. Therefore, the narrower beamwidth of all proposed radars and the more rapid scan of Type II are important.

Comment 3

Flights in the terminal area either taking off or landing -- Today this is a major problem to the airline industry. Since all thunderstorms present one or more potential problems, millions of dollars are lost each year by the Air Carriers and by the general public from operational delays and diversions with thunderstorms in the terminal area and approach corridors. It is safe to fly near some thunderstorms while others need to be avoided by many miles. Present-day radar cannot always differentiate between the two. High-level thunderstorms at Denver and desert terminals are typical examples. If Doppler radar can separate the "good guys" from the "bad buys", it has a potential of millions of dollars in savings to the aviation industry in addition to enhancing the safety of the operation. Since strong low-level wind shear associated with thunderstorms may be close to the ground and small scale in terms of the area surrounding an airport, a Doppler radar located some fifty to seventy-five miles from the terminal will contribute very little to the solution of this problem. Consideration must be given to locating Doppler close to large airports.

Flight planning for avoidance of en route conditions with reference to routings and altitudes -- The next generation of non-Doppler-type radar should be adequate for route selection to avoid thunderstorms or line squalls. A mix of non-Doppler with

Doppler radar in the system should be adequate for this requirement. Airborne radar would supplement the system when the flight is en route.

Comment 4

Our analysis of the detection of cells, clusters and significant cells has shown that the single most important radar parameter to maintain is the horizontal azimuth resolution. The three radar types, II, III and IV sacrifice horizontal resolution for the sake of reducing observation times constant within a 0.1 second dwell time. It would be better to operate with a 0.05 second dwell time and utilize the full azimuthal resolution provided by the antenna system. This could be accomplished within the accuracy limitations by a combined use of multiple frequencies within the S-band allocation and range integration. An S-band radar (2.8 GHz) with an antenna designed to minimize close-in sidelobe levels will have a one-way beamwidth of 1.1° (which should be used as a measure of azimuth resolution, not the two-way 0.7° value supplied in the table). The reflectivity and pulse pair estimates should be provided at 1° azimuth intervals.

Comment 5

Delays, diversions and cancellations due to thunderstorms are far more important to airline operations than low ceilings and visiblities. See effect of eastcoast storm on October 25, 1980. Eastern had 38 cancellations, diversions due to this "winter type" storm.

Comment 6

Doppler radar would be most useful, in my opinion, for detection of wind shears, gusts, and turbulent regions. I have included frontal and gust frontal windshifts in this category of turbulence. Doppler radar would also suggest areas of downdraft and updraft, and their strenths, which provide additional information on distinguishing severe from non-severe thunderstorms.

I am concerned about some degradation in the ability to continuously monitor dangerous echoes at low elevations. Are the cycle times fixed?

Comment 7

In comparing NEXRAD with these features to the WSR-57 system for the FAA application, we should presume that the FAA is making full use of the WSR-57. Although it is not as of right now, it should be by the time NEXRAD is ready to be deployed using the Enroute Weather Display System (EWEDS) and the Remote Weather Radar Display System (RWRDS). Hopefully, with some conservative hazardous weather algorithms, these systems will accrue safety benefits, reducing the threat of accidents due to embedded thunderstorms, in particular, for general aviation aircraft (e.g., reference the accident of March 24, 1972 involving a Cessna 210 near Atlanta, GA.).

In addition to more accurate algorithms, the elevation sampling will provide more timely warnings. Storm cells can build (culumus stage) and precipitation can break out (in the first echo region - typically about 20,000 feet) all without precipitation being detected by the WSR-57 at its low elevation sample for 15 to 20 minutes. Yet this cell can be a serious problem for a general aviation aircraft. Elevation sampling through this first echo region frequently (e.g., the FAA requirement is every 2.5 minutes) can provide a warning of such a cell earlier improving chances for its avoidance.

In addition, to aiding in turbulence avoidance, the Doppler capability of NEXRAD will aid in the avoidance of an additional aviation hazard associated with the airport area (i.e., during approach, landing, and take-off), the low level wind shear hazard. There is strong evidence that a Doppler NEXRAD radar located at or near an airport can detect and warn of hazardous shears due to thunderstorm qust qronts (reference Wilson, J., Carbone, R. and Serafin, R., 1980: Detection and Display of Wind Shear and Turbulence, 19th Conf. on Radar Meteor.). These types of shears are suspected of having caused several serious air carrier accidents during final approach.

HAIL

Comment 1

The presence of hailstones which are larger than raindrops can be recognized by the high reflectivity values associated with them. Because the hailshafts are small in dimension and transient in nature, time and space resolution of the measurements is important.

Comment 2

It is not likely that hail can be identified by using Doppler techniques. Present research would indicate that more likely procedures to identify hail will be derived from measurements at different polarizations or by dual-wavelength measurements.

Comment 3

With respect to the performance characteristics of the various optional designs shown in enclosure 1, I have grave reservations about all of them. Type II Doppler is clearly the best but hardly goes far enough. Without differential reflectivity, there is no way to get any significant improvements on rainfall measurement and flash flood detection or hail detection. Moreover, I have many questions about the long pulse length (and lack of flexibility), the long scan times, and evident lack of provision for faster scans in either RHI or PPI over limited sectors.

Comment 4

The aviation user desires information regarding the location and movement of hazardous weather including, heavy precipitation, hail, and severe turbulence. The WSR-57/EWEDS/RWRDS system will provide such information primarily using reflectivity at a single low elevation sample (with infrequent echo tops reports). The addition of automated elevation sampling will provide for superior information on the vertical nature of hazardous weather. There is strong evidence that this will permit improved hazardous weather algorithms regarding both hail (e.g., reference Lemon, L.R., 1978: On the Use of Storm Structure for Hail Identification, 18th Conf. on Radar Meteor.) and turbulence (e.g., reference Crane, R.K., 1979: Automatic Cell Detection and Tracking, IEEE Transactions on Geoscience Electronics, Vol. GE-17, No. 4). These improvements should improve both safety of flight (presuming that their probability of detection will be better than those based upon one elevation sample) and reduce delays by freeing up airspace declared as hazardous by unnecessarily conservative algorithms.

ICING

Comment 1

Icing is caused by supercooled water droplets which are too small to be detected by the radar. Their presence can be inferred when convective elements are observed above the 0 C isotherm. We have no idea of what fraction of icing situations are thus observable, but sensitivity and spatial resolution are important for depicting them.

Comment 2

It is not likely that Doppler measurements present any improvement to detection. Again improvement here may be found with orthogonal polarizations.

WINDS

Comment 1

Some idea of the wind in the vicinity of 700 mb can be obtained from a non-coherent radar by tracking small echoes. With Doppler capability the radial wind can be measured at any height within the echo areas. The extent to which the total wind field can be determined depends on the storm coverage.

Comment 2

Doppler capability is essential. Non-coherent techniques have proven essentially useless.

Comment 3

We have included clear air measurements of winds which have applications to air quality forecasting and forecasting the initiation of convection. Table I illustrates our opinion that the scanning procedure adopted should be a function of the phenomenon being observed. It seems unwise to restrict the system's operation to a single scanning procedure for all meteorological conditions.

Comment 4

Our assessment of Type IV only credits the system with factors 1) and 2) above. Types II and III, because they are both Doppler, include credit for the air motion measurement and factor 3) above. Type II is judged to be somewhat superior in this regard.

Comment 5

Doppler radar would be most useful, in my opinion, for detection of wind shears, gusts, and turbulent regions. I have included frontal and gust frontal windshifts in this category of turbulence. Doppler radar would also suggest areas of downdraft and updraft, and their strengths, which provide additional information on distinguishing severe fron non-severe thunderstorms.

I am concerned about some degradation in the ability to continuously monitor dangerous echoes at low elevations. Are the cycle times fixed?

Comment 6

In addition, to aiding in turbulence avoidance, the Doppler capability of NEXRAD will aid in the avoidance of an additional aviation hazard associated with the airport area (i.e., during approach, landing, and take-off), the low level wind shear hazard. There is strong evidence that a Doppler NEXRAD radar located at or near an airport can detect and warn of hazardous shears due to thunderstorm gust fronts (reference Wilson, J. H., Carbone, R. and Serafin, R., 1980: Detection and Display of Wind Shear and Turbulence, 19th Conf. on Radar Meteor.). These types of shears are suspected of having caused several serious air carrier accidents during final approach.

All of the above described benefits of NEXRAD for the FAA regard severe weather systems. However, such systems occur relatively infrequently. For the most part we have fair weather. Therefore, severe weather benefits are derived only a fraction of the time. One of the best reasons for NEXRAD to be a Doppler radar is to permit benefits to be derived during fair weather.

Analysis indicates that a 1 MW S-band radar can have a sensitivity sufficient to provide meaningful wind information for very low reflectance factors (e.g., negative dBz), reflectances representative of optically clear air with relatively few tracers. However, elevation samples have to be traded off against scan rate and dwell time in order to accomplish this. In this fair weather mode, a NEXRAD radar located at or near an airport could provide information regarding wind shears due to boundary layer effects and frontal movement. This would produce a safety benefit in fair weather (e.g., abrupt wind shifts due to warm front passage appears to have been associated with the Iberia Air Lines accident at Boston Logan Airport (NTSB-AAR-74-14). In addition, fair weather wind shifts can require runway configuration changes. If rapid wind shifts could be predicted by the NEXRAD radar, this could be of assistance in managing the traffic flow pattern and thereby derive a benefit in reduced delays due to the necessary runway changes.

FLASH FLOODS

Comment 1

Attempts to use radar operationally as an instrument for measuring areal rainfall have not been successful because serious uncertainties are inherent in the measurements. There is little doubt, however, that a reliable radar and digital processing system can be programmed to note situations when unusually intense storms persist over a watershed. Digital processing is crucial to this application for integrating total rainfall over time and area. High resolution in the vertical is important in that it extends the range of trustworthy measurements.

Comment 2

I have gone through the material you sent and have evaluated the proposed NEXRAD radar types II, III, and IV. Since none of the proposed designs is adequate for thunderstorm hazard detection as required by the FAA, I have added an additional design, designated as type A in the attached tables, having what I consider to be the desired characteristics. In establishing the new table, I have assumed that the maximum useful range for a 1^{o} beamwidth radar is 90 km for the precise measurement of precipitation (rain rate) and 180 km is the maximum range for all observations. At 180 km, the lowest elevation angle data are from heights between 3.4 and 6.6 km which are contaminated by ice. At longer ranges, the regions below the melting level will be below the horizon and undetectable by the radar.

Comment 3

On the other hand, I believe it is a fallacy to consider only the major hazards in assessing the value of NEXRAD. There are a host of other applications which are neglected in your documents which together provide major incremental benefits. Indeed, I am convinced that the combination of Doppler radar and mesoscale models hold the key to greatly improved forecasts of precipitation. When we think of a system to be in place for the next 2 decades, we can be certain that there will be many more benefits derived than can now be anticipated by even the most visionary scientists.

With respect to the performance characteristics of the various optional designs shown in enclosure 1, I have grave reservations about all of them. Type II Doppler is clearly the best but hardly goes far enough. Without differential reflectivity, there is no way to get any significant improvements on rainfall measurement and flash flood detection or hail detection. Moreover, I have many questions about the long pulse length (and lack of flexibility), the long scan times, and evident lack of provision for faster scans in either RHI or PPI over limited sectors.

Comment 4

The tables are reasonable self-explanatory but a few words of elaboration may be useful. First, you will notice that the categories of weather phenomena are substantially more numerous than those included in your matrix and include both severe and non-severe phenomena. Precipitation measurement is relevant to flash flood warnings as well as to precipitation accumulation measurements for hydrological and agricultural purposes.

Comment 5

Research into morphology of flood producing storms and data processing by new equipment may ultimately lead to identification of structure and flow characteristics which will vastly improve capabilities but little is known at this time. Polarization (ZDR) measurements may provide more accurate estimation of rainfall and rainfall rates than is possible with simply intensity measurements.

Comment 6

I strongly endorse the statements to the effect that on-site processing of even non-Doppler radar data greatly enhances the usefulness of the data for severe weather identification and particularly for flood prediction. Our experience in the past few years with such processing is that great benefits can accrue just from this activity. I also endorse the use of Doppler and non-Doppler mix for low risk areas.

Comment 7

It is important, when examining Table II, to recognize that the scores relate to the systems' capacities for making quantitative measurements and are not estimates of the real or perceived benefits that will be obtained from the forecasts subsequently issued. The cumulative scores give no weight to the relative importance of the phenomena. Finally, we agree with Atlas that dual-polarization capability may substantially enhance precipitation measurements and the ability to determine the phase of the precipitation.

Comment 8

I believe several important applications of Doppler radar technology should be added to any list of potential improvements in service to the public. Applications in optically clear air and more general application in widespread precipitation (such as boundary layer heights and Doppler velocities within that layer, as well as frontal location in very exact geometry) scream for attention by NEXRAD.

Comment 9

Difficulties in the information provided include the fact that the current WSR-57 radar uses a 4 us pulse width resulting in a 600 m pulse volume sampled (not 150 m as listed), a beam width of 2.2° (not 2°) and a PRF in the short pulse mode of 454 (not 658). The NEXRAD radars will likely have a variable pulse width, 150 m (as during JDOP) for velocity estimates within 250 km and a 600 m width for reflectivity estimates out to 450 km. Additionally, the comment that "research activities provide conclusive indications of the unique capabilities of Doppler to decipher the physical characteristics of severe winter storms, icing and flash floods", is an exaggeration at best. Some tentative investigations of flow in snow storms and bright bands (freezing levels) have been carried out by Doppler radar (typically multiple C band radars). Also, some correlation has been shown between high rainfall rates and large rainfall accumulation in mesocyclonic storms. However, "improved detection capability" for these phenomena has not been demonstrated (conclusively or otherwise).

Comment 10

One definite benefit would be gained from NEXRAD IV, the detection of flash floods in progress. Displays of time integrated reflectivity would really alert the forecasters to critical areas which they might overlook in hectic situations. I am including the flooding aspects of hurricanes in this category of flash floods.

HURRICANES

Comment 1

The WSR-57's do a good job of tracking the eye of a hurricane and showing the extent of the circulation around it. Addition of Doppler capability would add extremely valuable wind information. Digital data processing would permit spatial integration of rainfall rate which would yield an estimate of the total rate of release of latent heat, a quantity of significance to the development and behavior of the hurricane.

Comment 2

The Doppler information would be useful for estimating the strength of the winds, as well as the region of most intense winds.

Comment 3

One definite benefit would be gained from NEXRAD IV, the detection of flash floods in progress. Displays of time reflectivity would really alert the forecasters to critical areas which they might overlook in hectic situations. I am including the flooding aspects of hurricanes in this category of flash floods.

SEVERE WINTER STORM

Comment 1

Relatively little is known of the meso-structure of severe winter storms - making it difficult to estimate improvement. Doppler radar capability could be used to locate lines of wind shift accompanying fronts of winter cyclones. This could again be important to airport operations. In addition, Doppler radar provides horizontal wind information as a function of height which could be used in short term forecasting. The narrower beamwidth also permits detection of more intense snow areas.

Comment 2

The new, type A radar, uses both frequency and polarization to provide isolation between the Doppler and reflectivity channels. A by-product of the dual frequency, dual polarization scheme is additional information on the difference between reflectivities at vertical and horizontal polarization which can be used to separate regions with snow or ice from regions with rain (liquid only)[1,2]. The cost should be less than for radar type II (requires no polarization switch and shift in LQ but does not require an offset feed or second receiver.

Comment 3

Because of the relatively low reflectivity of snow and the importance of low level (often below the radar horizon) growth of hydrometeors in severe winter storms, such storms are not well depicted by radar and they can be observed only at very limited ranges. Since strong winds are an important feature in these storms, addition of the Doppler capability would be a strong plus towards determining the severity. Finer resolution would help some in extending the range of observations.

Comment 4

Difficulties in the information provided include the fact that the current WSR-57 radar uses a 4 us pulse width resulting in a 600 m pulse volume sampled (not 150 ms as listed), a beam width of 2.2° (not 2°) and a PRF in the short pulse mode of 454 (not 658). The NEXRAD radars will likely have a variable pulse width, 150 m (as during JDOP) for velocity estimates within 250 km and a f600 m width for reflectivity estimates out to 450 km. Additionally, the comment that "research activities provide conclusive indications of the unique capabilities of Doppler to decipher the physical characteristics of severe winter storms, icing and flash floods", is an exaggeration at best. Some tentative investigations of flow in snow storms and bright bands (freezing levels) have been carried out by Doppler radar (typically multiple C band radars). Also, some correlation has been shown between high rainfall rates and large rainfall accumulation in mesocyclonic storms. However, "improved detection capability" for these phenomena has not been demonstrated (conclusively or otherwise).

APPENDIX E

Radar Types, Characteristics, and Cost Estimates

INTRODUCTION

Five alternative radar configurations for NEXRAD have been identified. Their basic characteristics are summarized in Table 1. All radars have in common several assumptions. These assumptions are summarized in Table 2. Pertinent parameters are summarized in Table 3, for all five radars.

Sections below elaborate on these tabular summaries, and describe radars I-V in terms of their fundamental characteristics, coverage volume, scan strategy, weather detection and resolution capabilities.

Coverage rate and resolution are a function of the assumed scan strategy. The particular values in Table 3 are based on the scan strategies described in the pertinent Sections. These strategies attempt to meet accuracy requirements by maintaining dwell time constant at a nominal 100 msec, but at the expense of decreased coverage or data rate. Full 25^{o} elevation coverage and 5 minute data rate could be forced by increasing the antenna rotation rate above the values in Table 3, but severe degradation in azimuthal resolution would result for a constant dwell time, due to the increased smearing of the effective beamwidth. Alternately, accuracy could be sacrificed by decreasing dwell time, to yield full coverage and data rate at desired resolution.

A possible way to alleviate the situation is by use of more sophisticated waveforms. The data rates in Table 3 are based on estimating reflectivity and Doppler on alternative azimuth scans. This simple approach minimizes problems associated with ground clutter elimination and transmitter phase stability. A savings in time can be achieved by interlacing high and low PRF's on the same scan (for example, like the "batch" waveform used by NSSL). The amount of time saving and the implications on clutter rejection and transmitter stability need further study. For present purposes, however, the simpler scheme has been assumed.

RADAR I DESCRIPTION

Fundamental Characteristics and Principal Features

This radar attempts to meet most user requirements of coverage, resolution, and update rate for both reflectivity and Doppler. A 24' diameter antenna dish provides a one way beamwidth of 1^{o} in azimuth and elevation. The antenna forms five simultaneous beams on transmit and receive. The beams are spaced vertically at 5^{o} increments and are mechanically scanned in azimuth. Reflectivity and Doppler are measured on alternate azimuth scans, using low and

Technology Service Corporation

TABLE E-1

TENTATIVE RADAR CONFIGURATIONS FOR NEXRAD COSTING

RADAR	ANTENNA	TRANSMIT/REC	CHARACTERISTIC	PROD COST(K)
I	5 BEAM 1° BEAMWIDTH	FULL COHERENT ~2 FREQUENCY 5 RECEIVERS PPP 2 TRANSMIT	APPROXIMATES MOST REQUIREMENTS	$1,800
II	2 FEED DISH 1° BEAMWIDTH	FULL COHERENT 1 FREQUENCY 2 RECEIVERS PPP 1 TRANSMIT	SOME DATA RATE, RES. AND AVAILABILITY COMPROMISE	$ 850
III	1 FEED 1° BEAMWIDTH JDOP TYPE	FULL COHERENT 1 FREQUENCY 1 RECEIVER PPP 1 TRANSMIT	ADDITIONAL DATA RATE, SOME RES. AND AVAILABILITY, COMPROMISES	$ 700
IV	1 FEED 1° BEAMWIDTH	UPGRADABLE TO COHERENT 1 FREQUENCY 1 TRANSMIT	III WITHOUT DOPPLER CAPABILITY	$ 600
V	1 FEED 2.2° BEAMWIDTH	NON-COHERENT 1 FREQUENCY 1 TRANSMIT	CURRENT EQUIVALENT TO WSR-57	$ 290

PRODUCTION COST FOR RADAR, INCLUDING RECEIVERS, PPP, DVIP. NOT INCLUDING TOWER, SPARES, DOCUMENTATION. QUANTITY 100 IN 3 YEARS (FIRM CONTRACT)

Technology Service Corporation

Table E-2

COMMON ASSUMPTIONS

ALL CONFIGURATIONS HAVE THE FOLLOWING ASSUMPTIONS IN COMMON:

S-BAND (10.7 cm),
LINEAR-HORIZONTAL POLARIZATION,
CIRCULAR APERTURE

SIMPLE PULSE (NO PULSE COMPRESSION),
PULSE-MATCHED RECEIVER BANDWIDTH,
LOGARITHMIC RECEIVER 'CHARACTERISTIC' FOR REFLECTIVITY MEASUREMENTS, LINEAR (I,Q) OUTPUTS MAY BE USED
LINEAR RECEIVER CHARACTERISTIC FOR DOPPLER VELOCITY MEASUREMENT
SIMPLE MTI PROCESSING
SPATIAL (RANGE) AND TEMPORAL (PULSE-PULSE) AVERAGING OF REFLECTIVITY MEASUREMENTS
SOME BUILT IN TEST EQUIPMENT
REFLECTIVITY AND DOPPLER MAPS ARE OBTAINED ON ALTERNATE SCANS, AT LOW ELEVATIONS

CATEGORIES

SYSTEMS	CONFIGURATION CATEGORY
I	MULTI-BEAM, MULTI-RECEIVER DOPPLER
II, III	DUAL OR SINGLE BEAM, DOPPLER
IV	SINGLE BEAM, NON-DOPPLER, UPGRADABLE
V	OFF THE SHELF SYSTEMS

Table E-3

Pertinent Radar Parameters

Radar:	I	II	III	IV	V
Antenna:					
diameter (ft)	24'	24'	24'	24'	12'
half power beamwidth (1-way) θ_1	1°	1°	1°	1°	2.2°
number of beams	5	2	1	1	1
scan rate (rpm)	2	2.4	2.4	2.4	2.4
Transmitter:					
type	coh. dual	coh.	coh.	upgrad. to coh.	non-coh.
type of tube	klystron	klystron	klystron	klystron	magnetron
peak power (MW)	1.5	1.5	1.5	1.5	0.6
ave. power (kw)	1	1	1	1	1
pulse width (usec)	1	1	1	1	1
pulse repetition frequency (pps)	1000/300	1000/300	1000/300	300	150/600
Receiver:					
number of receivers	5	2	1	1	1
processing channels per receiver					
linear	yes	yes	yes	add-on	no
logarithmic	yes	yes	yes	yes	yes
Signal Processing:					
**linear receiver channels:					
MTI	1	1	1	add-on	-
pulse-pair processors	5	2	1	add-on	-
**logarithmic receiver channels					
MTI	1	1	1	1	0
DVIP	5	2	1	1	1
Coverage and Resolution:					
update time (minutes)	5	6.2	11.7	8.3	5
elevation					
coverage	0-25°	0-20°	0-20°	0-20°	0-24°
resolution*, θ_e	.7°	.7°	.7°	.7°	1.6°
azimuth					
coverage	0-360°	0-360°	0-360°	0-360°	0-360°
resolution, θ_a	1.2°	1.5°	1.5°	1.5°	1.3°
range					
coverage	250 km	250 km	250 km	250 km	250 km
resolution	.6 km	.6 km	.6 km	.6 km	.6 km
maximum altitude (ft)	70,000	70,000	50,000	70,000	70,000

*It may be desireable to increase this to 1.0° as described in the Section on the scanning and beamwidth dilemma.

**May be combined.

high PRF continuous pulse train waveforms. After each pair of azimuth scans and the 5 beams are stepped in elevation. This is performed mechanically.

The transmitter is fully coherent, and is based on the varian 87E klystron. Power requirements are minimized by decreasing the power transmitted on the upper beams, where maximum range will be smaller. Dual transmitter tubes are used primarily for redundancy, and thus increased availability. Dual frequency operation also becomes a viable option with dual transmitters, pending sufficient bandwidth allocation. Dual frequency operation allows the data rate to be increased, either by simultaneous collection of reflectivity and Doppler data on separate frequency channels, or by pulse-to-pulse frequency diversity on the reflectivity waveform to obtain more independent pulses per unit time.

Five parallel receivers are necessary, each with two parallel processing channels. Reflectivity is estimated when the low PRF is used by incoherent averaging of logarithmic envelope detection outputs. Doppler mean velocity and spectral width are estimated by using a high PRF waveform with a linear, coherent quadrature receiver, followed by a pulse-pair processor. Each of the two processing channels includes some form of ground clutter cancelling circuitry.

Coverage Volume, Scan Strategy, and Update Time

The coverage volume of this radar is bounded by elevations from horizon to 25°, to a maximum altitude of 70,000 feet and maximum range of 250 km.* The volume is swept in 5 minutes, using the following scan strategy. The antenna is mechanically scanned in azimuth at 2 revolutions per minute. On the first azimuth scan, the 5 beams are directed at elevations of 1°, 6°, 11°, 16°, and 21°. The low PRF waveform is used to obtain a reflectivity map on each of the 5 beams, out to the perimeter of the coverage volume. On the second azimuth scan, the PRF is increased to the high rate suitable for the desired maximum unambiguous velocity measurement. Selection of the particular value of high PRF may be adaptively based on the reflectivity map obtained at the low PRF on the previous scan. Following the high PRF scan, the 5 beams are stepped 1° in elevation, and the process repeated until the full 25° elevation has been scanned. The scan strategy is summarized in Table 4, in which it is seen that 10 rotations are required to complete the cycle, or an update time of 5 minutes between volume scans.

Weather Detection and Resolution Capabilities

Reflectivity estimates are obtained by averaging the logarithmic receiver channel outputs. Multiple pulses and range cells are averaged to provide the required accuracy. Pulse-to-pulse

* Roughly the range at which 0 dB S/N is obtained on a 10 dBZ rain cell

Table E-4

Scan Strategy, Radar I

Rotation	Beam 1	Beam 2	Beam 3	Beam 4	Beam 5	PRF
1	1°	6°	11°	16°	21°	low
2	1	6	11	16	21	high
3	2	7	12	17	22	low
4	2	7	12	17	22	high
5	3	8	13	18	23	low
6	3	8	13	18	23	high
7	4	9	14	19	24	low
8	4	9	14	19	24	high
9	5	10	15	20	25	low
10	5	10	15	20	25	high

averaging is implemented for a nominal 100 msec integration time, during which about 10 independent reflectivity samples are obtained per range cell. By averaging over 4 adjacent range bins as well, approximately 40 independent reflectivity samples are obtained, which provide a reflectivity accuracy of about 1 dBZ as limited by statistical fluctuations of the weather return signals. The spati l resolution cell dimensions on which these measurements are ot ained are governed by the effective two-way beamwidths and the range extent of four resolution cells. The elevation beamwidth is about 0.7^{o} (two-way), and the effective azimuth beamwidth is about 1.2^{o}, including the broadening affects of scanning. Four range cells are about 0.6 km at a 1 usec pulse length.

Velocity estimate accuracy is also determined by the dwell time. Using a formula from (1), the standard deviation of the velocity estimate will be about 1m/sec for typical spectral widths. Standard deviation of the velocity spectrum width estimate will also be on the order of 1 m/sec.

(1) Zrinc, D.S., 1977, "Spectral Moment Estimates from Correlated Pulse Pairs" IEEE Transactions AES-13, 344-354.

RADAR II DESCRIPTION

Fundamental Characteristics and Principal Features

This radar is basically a two-beam version of Radar I or Radar III. The aperture is 24' in diameter, but only two simultaneous beams are formed. They are spaced vertically by 5^{o} and mechanically scanned in azimuth. At low elevations, reflectivity and Doppler maps are obtained on alternate azimuth scans. At higher elevations, maximum range is shorter, and reflectivity and Doppler are measured on the same scan using a common PRF.

The transmitter is identical to the Radar I transmitter, except that only a single transmitter tube is used. Receiver and signal processing is also similar, but only two receivers are necessary.

Coverage Volume, Scan Strategy, and Update Time

Maximum elevation covered with this radar is 20^{o}. Coverage at high elevation angles is sacrificed in this radar in an attempt to keep update time reasonable, and yet utilize a two-beam system. Coverage to 70,000 feet altitude and to a maximum range of 250 km is maintained. The volume is swept in 6.2 minutes, with a rotation rate of 2.4 rpm and a 15 rotation scan strategy as shown in Table 5. On the first rotation, the 2 beams are directed at elevations of 1^{o} and 6^{o}, and reflectivity is mapped at each of these elevations using the low PRF waveform. On the second rotation, a high PRF waveform is used to map Doppler. The beam positions are then raised by 1^{o}, and reflectivity and Doppler maps obtained at 2^{o}

Table E-5

Scan Strategy for Radar II

Rotation	Beam 1	Beam 2	PRF
1	1	6	low
2	1	6	high
3	2	7	low
4	2	7	high
5	3	8	low
6	3	8	high
7	4	9	low
8	4	9	high
9	5	10	low
10	5	10	high
11	11	16	high
12	12	17	high
13	13	18	high
14	14	19	high
15	15	20	high

and 7° on the next two rotations. This process is continued until elevation 5° and 10° have been mapped. At this point, the beams are raised to 11° and 16°, and a high PRF waveform is used for simultaneous estimation of reflectivity and Doppler. This is possible because of the decreased maximum range requirement at elevations above 10°. In 5 additional rotations the region from 11° to 20° elevation is thus mapped.

Weather Detection and Resolution Capabilities

Reflectivity and Doppler maps are obtained using the same processing concepts as for Radar I. By keeping the dwell time the same as in Radar I, accuracies of about 1 dB in reflectivity and 1 m/sec in velocity and spectral width estimates are maintained.

The spatial resolution cell size increases to about 1.5° in the azimuth direction due to the higher rotation rate of the antenna. The two-way elevation beamwidth is 0.7°, and four range cells remain at 0.6 km for a 1 usec pulse.

Somewhat more power would be transmitted in the lower of the two beams. This would be accomplished by a power divider between the transmitter and the two antenna ports.

RADAR III DESCRIPTION

Fundamental Characteristics and Principal Features

This is a single beam system of the type recommended by the Jc nt Doppler Operational Project (JDOP). It has a 24' dish to pro ‿e a single 1° beam on transmit and receive. Reflectivity and Doppler maps are obtained on alternate scans, using low and high PRF's, respectively.

The transmitter is a single tube version. A single receiver, with parallel reflectivity and Doppler estimation channels, is used. Reflectivity estimation is obtained by averaging logarithmic envelope detector outputs. Doppler velocities and spectral widths are estimated with pulse-pair processing of linear I and bipolar video.

Coverage Volume, Scan Strategy, and Update Time

Elevation coverage up to 20°, a maximum altitude of 50,000 feet, and a 250 km maximum range define the coverage volume for this radar. Relative to Radar I, high elevation and high altitude coverage have been sacrificed. In addition, the need to search the volume with only a single 1° beam leads to a very low data update rate of 11.7 minutes.

The scan strategy is essentially similar to that for Radar II, except that only a single beam is employed. The scan sequence is tabulated in Table 6. Additionally, the lower maximum altitude

Table E-6

Scan Strategy for Radar III

Rotation	Beam 1	PRF
1	1	low
2	1	high
3	2	low
4	2	high
5	3	low
6	3	high
7	4	low
8	4	high
9	5	low
10	5	high
11	6	low
12	6	high
13	7	low
14	7	high
15	8	low
16	8	high
17	9	high
18	10	high
19	11	high
20	12	high
21	13	high
22	14	high
23	15	high
24	16	high
25	17	high
26	18	high
27	19	high
28	20	high

decreases the elevation at which the transition is made from two PRF's to a single PRF, from 10° to 8°. Thus a full volume scan is made in 28 rotations, which require 11.7 minutes at 2.4 rpm.

Weather Detection and Resolution Capabilities

These are identical to the values for Radar II.

RADAR IV DESCRIPTION

Fundamental Characteristics and Principal Features

This radar is identical to Radar III, except that the coherent Doppler channel of the receiver is not implemented. The radar is thus a single-beam, non-Doppler system which is capable of being upgraded to a Type III radar at a future point in time.

Capabilities and Performance

Coverage Volume, Scan Strategy, and Update Time

Because only reflectivity is to be mapped, the use of only a single value of PRF is required. Thus the scan strategy is exceedingly simple. It is summarized in Table 7. Twenty rotations are necessary for volume coverage to 20°, which consume 8.3 minutes at 2.4 rpm.

Weather Detection and Resolution Capabilities

Reflectivity accuracies of 1 dBZ are obtained by averaging logarithmic envelope returns over 4 range cells, and for a nominall 100 msec dwell. The spatial resolution cell is .7° in elevation by 1.5° effective beamwidth in azimuth, by 0.6 km in range.

RADAR V

Fundamental Characteristics and Principal Features

This radar is a current replacement for the existing WSR-57 radars, using contemporary technology. Examples are he Raytheon WSR-77 and the Enterprise WSR-74S. It utilizes a 12' aperture to obtain a single 2.2° one-way beam. It is a non-Doppler radar, and is not intended for future upgrading to Doppler capability. (Enterprise is developing an upgradable version). Thus the transmitter is non-coherent and based on a single magnetron tube. Reflectivity estimation is obtained by averaging logarithmic envelope detector outputs.

Coverage Volume, Scan Time, and Update Time

Reflectivity measurements only are obtained, and like Radar IV, a simple scan stretegy is used. It is summarized in Table 8. The

Table E-7

Scan Strategy for Radar IV

Rotation	Beam	PRF
1	1°	low
2	2	low
3	3	low
4	4	low
5	5	low
6	6	low
7	7	low
8	8	low
9	9	low
10	10	low
11	11	low
12	12	low
13	13	low
14	14	low
15	15	low
16	16	low
17	17	low
18	18	low
19	19	low
20	20	low

Table E-8

Scan Strategy for Radar V

Rotation	Beam	PRF
1	2°	low
2	4	low
3	6	low
4	8	low
5	10	low
6	12	low
7	14	low
8	16	low
9	18	low
10	20	low
11	22	low
12	24	low

wider beam allows 24° of elevation coverage in 12 scans, by spacing successive scans at 2° elevation separation. At a rotation rate of 2.4 rpm, a 5 minute update time is achieved.

Weather Detect=ion and Resolution Capabilities

Reflectivity estimates are obtained with a nominal 1 dBZ accuracy, by averaging 4 range cells together over a 100 msec dwell time. Spatial resolution is 1.5° in elevation (two-way beamwidth) and 1.8° in azimuth. At a 1 usec pulse length, 4 range cells cover approximately 0.6 km. Due to lower power and antenna gain, the sensitivity of the system is lower than the other four systems.

THE NEXRAD TRANSMITTER

The development of a new high power transmitter tube for a radar is a costly and risky process. Fortunately, there is a device in wide use that can meet the NEXRAD requirements. It is the Varian 87E klystron. This is the transmitter used in the FAA ASR-8 terminal radar and in some Navy systems. The manufacturer claims about 40,000 hour measured life (over 4 years continuous) in its present form. This figure can easily be checked. The pertinent characteristics of the current tube are listed below. Spec numbers are in parenthesis. Projected values of a modification program are also shown.

Frequency Band	2.7-2.9 GHz	(1)
Instantaneous Bandwidth	37 (15) MHz	40 No Problem
Peak Power	1.6 (1.5) MW	2.0 No Problem
Average Power	3.5 Kw	3.5
Gain	53 dB	
Power In	5 W	

(1) The tube could be modified to cover 2.7-3.0 GHz, but this would be about an 18 month program.

Thus, relating the above to the typical JDOP radar, the power is somewhat higher than the minimum and as such would easily meet requirements of Radars II, III and IV. It could also be modified to meet the higher power requirements of Radar I possibly at some sacrifice in availability. The choice of a dual or diplex version of the transmitter using the existing tube is to increase availability of the whole transmitter and make the devices common for all "coherent" NEXRADS as well as ASR-8's, etc. Thus, the diplex Radar I has slightly higher production cost than for a single system, but lower development and spares costing.

The same general reasoning went into the selection of the 87E for Radar IV. An injection locked magnetron transmitter could be developed for future upgrading whose production cost would be lower. However, the increased development costs, spares, logistic problems, etc., would negate most of the cost savings.

It must be remembered that a power tube cost is only about 1/4 of the transmitter, and that overall transmitter MTBF is much less than the final tube alone.

THE SCANNING AND BEAMWIDTH DILEMMA

The extension of the JDOP Radar to an operational system presents some difficult trade-offs between angular resolution (beamwidth), scan rate, accuracy and the volumetric data rate. To oversimplify the JOR, the following are currently hard requirements:

(1) range coverage to 450 km in 1 km or better increments;

(2) 3D coverage to 21 km altitude in 1 km or better increments;

(3) volumetric coverage in 5 minutes with some need for 2.5 minutes;

(4) accuracies of about 1 dB in dBZ, V, and σ_v;

(5) vertical extent accuracy of about 1/2 km,

The implied requirements;

(6) an effective beamwidth, θ_e, of 1.0 to 1.2^o for distant recognition of mesocyclones plus an implication that this is required for storm tops. Note that $\theta_e = 0.707\theta_1$, where θ_1 is the conventional one way beamwidth.

(7) relatively low azimuth sidelobes to keep high reflectivity storm cells from appearing at other angles and low first few antenna sidelobes in elevation to minimize ground clutter.

The dilemma results in that if a JDOP type radar with a 24-foot dish is placed in a spiral scan mode, there will be a considerable azimuth smearing in attempting to maintain the volumetric coverage to less than 5-6 minutes. This results from the minimum time required per beam position to achieve the necessary accuracies in Z, V, and σ_v. This is illustrated in Table 3. There are various strategies to reduce this time, each of which has implications on other requirements:

(1) Interlacing reflectivity and Doppler waveforms on a single frequency saves some time, but it tends to reduce the phase and amplitude stability of the transmitter.

(2) Operating with two frequencies is somewhat better, but

causes more interference between radars.

(3) Reduction of maximum range to 250km helps.

(4) Looking at "every other" beam in elevation also helps, but would yield a poor height indication and poor storm top accuracy.

Multiple beam systems obviously help the data rate problem. A dual feed dish as in Radar II is illustrated on Table 3 to half the volume scan time. Alternately, it could be used in tornado prone areas to reduce Θ_e to the desired level. This would be accomplished by merely reducing the azimuth scan rate. As expected, a 5 beam system (I) could be utilized to reduce both volume scan time and Θ_e.

Looking again at the table, one notes that for II and III, $\Theta_e=1.5^o$ with a 1^o beamwidth (Θ_1). While not stated as such, the effective elevation beamwidth is only 0.7^o. This is the reverse of the desired ratio to detect mesocyclones. The theoretically correct way is to vertically scan. Neglecting mechanical problems, the azimuth scan period would be 2.5 or 5 minutes with a vertical "zig-zag".

Obviously, a mechanical scan at 10Hz is not practical, but an electronic scan is. Without a discourse on the subject, the practical way to do this is with frequency scan in elevation. This is a common technique in the military and is used by the operational SPS-48, SPS-52 and the MPQ-32. While this sounds impractical from a frequency allocation basis, remember that the horizon beam is always at a single frequency. All other beams point up in elevation and the interference is on a sidelobe to sidelobe basis. The elevation scan would be on a step scan basis, and there would not even be any elevation smearing. Thus, the antenna size could be reduced to 16-feet and with $\Theta_1= \emptyset_1 = 1.5^o$, $\Theta_e= \emptyset_e = 1.05^o$.

A 16-foot frequency scanned antenna would cost about $600K in production compared to a 24-foot mechanical at about $900K. Transmitter costs would increase only slightly.

If the 2.7 to 2.9 GHz band is too crowded, it may be possible to go to the 2.4 GHz band. The aperture size would go to 18 to 20 feet, but production costs would be about the same.

The above is a drastic recommendation, but there are less drastic results that fall out of the same reasoning. Radars II and III are planned for about a 1^o step in elevation. Since there is no elevation smearing, $\emptyset_e$ could be increased to 1^o ($\emptyset_1$ to 1.4^o) and achieve a more uniform volume coverage. If the reflector size is held constant, the first sidelobes could be reduced by 5 dB (10 dB - two way), and the land clutter reduced. The number of elevation cuts could also be reduced. While this reduces resolution in elevation, it does not imply that storm top accuracy requirements cannot be met. Any NEXRAD storm top algorithm should include beam splitting of some type that should achieve an accuracy of about 1/4 beamwidth.

RADAR COSTING

The production costs for the radar portions of the NEXRAD were derived by Technology Service Corporation employees involved in current Military radar programs plus the assistance of several major hardware manufacturers. Early Cost data supplied by NSSC and Transportation System Center to the JSPO were used to slightly modify and amplify some costs. A key uncertainty is the use of a production lot of 100 for the cost base. A fixed (non-cancellable) contract for that quantity of radars is extremely rare today and most surface radars are procured in smaller quantities without tooling for large production. As a result, many estimates are biased on whether the estimator believes that the procurement will really occur in quantities of 100. Another significant uncertainty results from the availability specification.

Since several of the scenarios include both Doppler and non-Doppler radars at different sites, Radars (I-IV) have substantial commonality of parts. The transmitter, receiver, synchronizer, maintenance console, A/D's etc. are costed with that assumption. With this assumption, mixes of radars will have production costs that are only slightly higher than if all one system was procured while the development costs are slightly lower. Optimization of each radar as if it were the only version, would thus have little or no overall effect on Program costing.

The costs were then checked against current procurements for comparable radars such as the ASR-8, TRACS, plus military equivalents.

Appendix F

Calculation and Results
--Investment Analysis

Part I - The Investment Model

Part II - Tables of Results of Calculations of Return on Investment -

Investment Models

A. The "INVEST" Model

Approval was received from the COTR under this Contract to use an investment model "INVEST" that has been developed within FAA to compare alternative investment opportunities. The introductory information supplied with the INVEST documentation states:

> "INVEST is a computer program which uses estimated and known information about investment alternatives which differ in the distribution of their costs. INVEST genenates several numbers which measure the productivity, or return per dollar for each alternative. INVEST can automatically vary each input estimate over a prescribed range for the purposes of a sensitivity analysis. By handling the "workhouse" aspects of the analysis, INVEST permits a more extensive conceptual treatment. The analysis can then be superior in both flexibility and accuracy.
>
> The formulae used by INVEST are standard present value conversions. These correlate cash flow items occuring at various times to an equivalent amount occurring in a year designated the "present". This accounts for the assumption that funds invested will increaase in value over time as a result of their use. The rate of increase, expressed as annual compound interest rate, is the <u>rate of return</u> on the investment. The interest rate used to compute the present values is the <u>discount rate</u> (discount factor). This factor relates a future amount to the present value which would genrate it. The standard discount rate used by INVEST is 10%, as per OMB guidelines."

B. A "Sonicraft Investment Model"

The INVEST model has been designed to compare pairs of alternatives. In order to compare the seven scenarios that have been postulated for this study, another computer program was developed. This program also uses standard net present value formulations but employs continuous rather than discrete discounting.

Continuous discount formulae are employed since the benefits which are expected to accrue will accrue throughout the year rather than at year end. The formulation to compute the net present value is:

$$PV = \sum CF_n(e^{-in})$$

where PV = present value

CF_n = cash flows for period n (cash outlays negative)

i = interest rate (as a fraction)

N = total number of periods

n = period index

The discount rate of 10%, prescribed by the COTR (based on OMB Circular A-94) has been employed in the analysis. Computation at other discount rates have been made to determine the sensitivity of the analysis to the discount rate chosen.

Zimmerman, D.C., in "Economic Analysis Procedures for ADP", March 1980, Navy Data Automation Command comments:

> "Even when there is a little disagreement about the investment's prospective costs and benefits, the choice of the discount rate figure may make the difference between acceptance and rejection. A low discount rate gives little attention to the time value of money. Investment costs incurred during the early years of a project life can be easily offset by benefits achieved in the late years. Thus, a low discount rate would tend to expand the number of public investment projects that would appear feasible, thereby causing many public projects with low returns to be

undertaken at the expense of more productive investments in the private sector. The net result of this would be to lower the rate of national economic growth.

A high discount rate, on the other hand, would tend to place a greater emphasis on today's costs. Thus, savings achieved in the out-years would have little impact on off-setting investment costs. The net result would be fewer government investments.

The proper criterion on which to judge the desirability of a government project, from the point of view of the general welfare, is the value of the opportunitties which the private secttor must pass by when resources are withdrawn from that sector. A government project is desirable if, and only if, the value of the net benefits it promises exceeds the cost of the lost productive opportunities which that investment causes. The correct discount rate for the evaluation of a government project is the percentage rate of return that the resources used would otherwise provide in the private sector.

The 10% discount rate implicity escalates constant dollar cost estimates at a normal rate. Therefore, the FAA generally does not include inflation in their economic investment analyses. If inflation were to be considered, only a differential rate would be utilized, i.e., the expected difference between the average long-term rate for the particular cost or cost-element and the normal rate.

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Table F-1

NET PRESENT VALUE
THIS COMPUTATION FOR SCENARIO 1-WITH TOTAL NON-RECURRING
COSTS OF $568 MILLION

INVESTMENT (OUTLAY)=$ 0
NUMBER OF YEARS 25
REQUIRED RATE OF RETURN(DISCOUNT RATE) R= 10 %

CASH FLOW -
OUTFLOWS ARE NEGATIVE

			VALUES OF NET COST OR BENEFIT FOR THE YEAR	CUMULATIVE	DISCOUNT FACTORS
1	1983	-2.40000E+007	-2.18182E+007	.909091	.909091
2	1984	-6.00000E+007	-7.14050E+007	1.73554	.826447
3	1985	-7.50000E+007	-1.27754E+008	2.48685	.751315
4	1986	-1.15000E+008	-2.06300E+008	3.16987	.683014
5	1987	-1.30000E+008	-2.87020E+008	3.79079	.620922
6	1988	-1.64000E+008	-3.79594E+008	4.35526	.564474
7	1989	2.00000E+008	-2.76962E+008	4.86842	.513159
8	1990	5.90000E+008	-1.72243E+006	5.33493	.466508
9	1991	5.90000E+008	2.48496E+008	5.75902	.424098
10	1992	5.90000E+008	4.75966E+008	6.14457	.385544
11	1993	5.90000E+008	6.82758E+008	6.49506	.350495
12	1994	5.90000E+008	8.70751E+008	6.81369	.318632
13	1995	5.90000E+008	1.04165E+009	7.10336	.289665
14	1996	5.90000E+008	1.19702E+009	7.36669	.263332
15	1997	5.90000E+008	1.33826E+009	7.60608	.239393
16	1998	5.90000E+008	1.46666E+009	7.82371	.21763
17	1999	5.90000E+008	1.58339E+009	8.02155	.197845
18	2000	5.90000E+008	1.68951E+009	8.20141	.179859
19	2001	5.90000E+008	1.78598E+009	8.36492	.163509
20	2002	5.90000E+008	1.87368E+009	8.51357	.148644
21	2003	5.90000E+008	1.95340E+009	8.64869	.135131
22	2004	5.90000E+008	2.02588E+009	8.77154	.122846
23	2005	5.90000E+008	2.09177E+009	8.88322	.111679
24	2006	5.90000E+008	2.15167E+009	8.98474	.101525
25	2007	5.90000E+008	2.20613E+009	9.07704	.0922965

NET PRESENT VALUE = $ 2.20613E+009

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Table F-2

NET PRESENT VALUE
THIS COMPUTATION FOR SCENARIO 2-WITH TOTAL NON-RECURRING
COSTS OF $422 MILLION

INVESTMENT (OUTLAY)=$ 0
NUMBER OF YEARS 25
REQUIRED RATE OF RETURN(DISCOUNT RATE) R= 10 %

		CASH FLOW - OUTFLOWS ARE NEGATIVE	VALUES OF NET COST OR BENEFIT FOR THE YEAR	CUMULATIVE	DISCOUNT FACTORS
1	1983	-2.40000E+007	-2.18182E+007	.909091	.909091
2	1984	-6.00000E+007	-7.14050E+007	1.73554	.826447
3	1985	-7.50000E+007	-1.27754E+008	2.48685	.751315
4	1986	-1.00000E+008	-1.96055E+008	3.16987	.683014
5	1987	-1.20000E+008	-2.70566E+008	3.79079	.620922
6	1988	-4.30000E+007	-2.94838E+008	4.35526	.564474
7	1989	2.00000E+008	-1.92206E+008	4.86842	.513159
8	1990	4.00000E+008	-5.60310E+006	5.33493	.466508
9	1991	5.74000E+008	2.37829E+008	5.75902	.424098
10	1992	5.74000E+008	4.59132E+008	6.14457	.385544
11	1993	5.74000E+008	6.60315E+008	6.49506	.350495
12	1994	5.74000E+008	8.43210E+008	6.81369	.318632
13	1995	5.74000E+008	1.00948E+009	7.10336	.289665
14	1996	5.74000E+008	1.16063E+009	7.36669	.263332
15	1997	5.74000E+008	1.29804E+009	7.60608	.239393
16	1998	5.74000E+008	1.42296E+009	7.82371	.21763
17	1999	5.74000E+008	1.53652E+009	8.02155	.197845
18	2000	5.74000E+008	1.63975E+009	8.20141	.179859
19	2001	5.74000E+008	1.73362E+009	8.36492	.163509
20	2002	5.74000E+008	1.81894E+009	8.51357	.148644
21	2003	5.74000E+008	1.89650E+009	8.64869	.135131
22	2004	5.74000E+008	1.96702E+009	8.77154	.122846
23	2005	5.74000E+008	2.03112E+009	8.88322	.111679
24	2006	5.74000E+008	2.08940E+009	8.98474	.101526
25	2007	5.74000E+008	2.14237E+009	9.07704	.0922965

NET PRESENT VALUE = $ 2.14237E+009

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Table F-3

NET PRESENT VALUE
THIS COMPUTATION FOR SCENARIO 3-WITH TOTAL NON-RECURRING COSTS OF $399 MILLION

INVESTMENT (OUTLAY)=$ 0
NUMBER OF YEARS 25
REQUIRED RATE OF RETURN(DISCOUNT RATE) R= 10 %

CASH FLOW -
OUTFLOWS ARE NEGATIVE

			VALUES OF NET COST OR BENEFIT FOR THE YEAR	CUMULATIVE	DISCOUNT FACTORS
1	1983	-2.40000E+007	-2.18182E+007	.909091	.909091
2	1984	-6.00000E+007	-7.14050E+007	1.73554	.826447
3	1985	-7.50000E+007	-1.27754E+008	2.48685	.751315
4	1986	-1.00000E+008	-1.96055E+008	3.16987	.683014
5	1987	-1.20000E+008	-2.70566E+008	3.79079	.620922
6	1988	-2.00000E+007	-2.81855E+008	4.35526	.564474
7	1989	2.00000E+008	-1.79223E+008	4.86842	.513159
8	1990	4.80000E+008	4.47004E+007	5.33493	.466508
9	1991	4.80000E+008	2.48268E+008	5.75902	.424098
10	1992	4.80000E+008	4.33329E+008	6.14457	.385544
11	1993	4.80000E+008	6.01566E+008	6.49506	.350495
12	1994	4.80000E+008	7.54509E+008	6.81369	.318632
13	1995	4.80000E+008	8.93549E+008	7.10335	.289665
14	1996	4.80000E+008	1.01995E+009	7.36669	.263332
15	1997	4.80000E+008	1.13486E+009	7.60608	.239393
16	1998	4.80000E+008	1.23932E+009	7.82371	.21763
17	1999	4.80000E+008	1.33428E+009	8.02155	.197845
18	2000	4.80000E+008	1.42062E+009	8.20141	.179859
19	2001	4.80000E+008	1.49910E+009	8.36492	.163509
20	2002	4.80000E+008	1.57045E+009	8.51357	.148644
21	2003	4.80000E+008	1.63531E+009	8.64869	.135131
22	2004	4.80000E+008	1.69428E+009	8.77154	.122846
23	2005	4.80000E+008	1.74788E+009	8.88322	.111679
24	2006	4.80000E+008	1.79662E+009	8.98474	.101526
25	2007	4.80000E+008	1.84092E+009	9.07704	.0922965

NET PRESENT VALUE = $ 1.84092E+009

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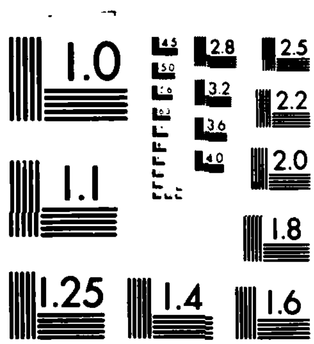

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table F-4

NET PRESENT VALUE
THIS COMPUTATION FOR SCENARIO 4-WITH TOTAL NON-RECURRING
COSTS OF $395 MILLION

INVESTMENT (OUTLAY)=$ 0
NUMBER OF YEARS 25
REQUIRED RATE OF RETURN(DISCOUNT RATE) R= 10 %

CASH FLOW -
OUTFLOWS ARE NEGATIVE

		CASH FLOW	VALUES OF NET COST OR BENEFIT FOR THE YEAR	CUMULATIVE	DISCOUNT FACTORS
1	1983	-2.40000E+007	-2.18182E+007	.909091	.909091
2	1984	-6.00000E+007	-7.14050E+007	1.73554	.826447
3	1985	-7.50000E+007	-1.27754E+008	2.48685	.751315
4	1986	-1.10000E+008	-2.02885E+008	3.16987	.683014
5	1987	-1.00000E+008	-2.64977E+008	3.79079	.620922
6	1988	-2.60000E+007	-2.79654E+008	4.35526	.564474
7	1989	2.00000E+008	-1.77022E+008	4.86842	.513159
8	1990	4.50000E+008	3.29067E+007	5.33493	.466508
9	1991	5.31000E+008	2.58103E+008	5.75902	.424098
10	1992	5.13000E+008	4.55887E+008	6.14457	.385544
11	1993	5.31000E+008	6.42000E+008	6.49506	.350495
12	1994	5.31000E+008	8.11193E+008	6.81369	.318632
13	1995	5.31000E+008	9.65005E+008	7.10336	.289665
14	1996	5.31000E+008	1.10483E+009	7.36669	.263332
15	1997	5.31000E+008	1.23195E+009	7.60608	.239393
16	1998	5.31000E+008	1.34751E+009	7.82371	.21763
17	1999	5.31000E+008	1.45257E+009	8.02155	.197845
18	2000	5.31000E+008	1.54807E+009	8.20141	.179859
19	2001	5.31000E+008	1.63490E+009	8.36492	.163509
20	2002	5.31000E+008	1.71383E+009	8.51357	.148644
21	2003	5.31000E+008	1.78558E+009	8.64869	.135131
22	2004	5.31000E+008	1.85081E+009	8.77154	.122846
23	2005	5.31000E+008	1.91011E+009	8.88322	.111679
24	2006	5.31000E+008	1.96402E+009	8.98474	.101526
25	2007	5.31000E+008	2.01303E+009	9.07704	.0922965

NET PRESENT VALUE = $ 2.01303E+009

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Table F-5

NET PRESENT VALUE
THIS COMPUTATION FOR SCENARIO 5-WITH TOTAL NON-RECURRING
COSTS OF $371 MILLION

INVESTMENT (OUTLAY)=$ 0
NUMBER OF YEARS 25
REQUIRED RATE OF RETURN(DISCOUNT RATE) R= 10 %

CASH FLOW -
OUTFLOWS ARE NEGATIVE

			VALUES OF NET COST OR BENEFIT FOR THE YEAR	CUMULATIVE	DISCOUNT FACTORS
1	1983	-2.40000E+007	-2.18182E+007	.909091	.909091
2	1984	-6.00000E+007	-7.14050E+007	1.73554	.826447
3	1985	-7.50000E+007	-1.27754E+008	2.48685	.751315
4	1986	-1.10000E+008	-2.02885E+008	3.16987	.683014
5	1987	-1.02000E+008	-2.66219E+008	3.79079	.620922
6	1988	1.00000E+008	-2.09772E+008	4.35526	.564474
7	1989	2.00000E+008	-1.07140E+008	4.86842	.513159
8	1990	4.39000E+008	9.76571E+007	5.33493	.466508
9	1991	4.39000E+008	2.83836E+008	5.75902	.424098
10	1992	4.39000E+008	4.53090E+008	6.14457	.385544
11	1993	4.39000E+008	6.06957E+008	6.49506	.350495
12	1994	4.39000E+008	7.46836E+008	6.81369	.318632
13	1995	4.39000E+008	8.73999E+008	7.10335	.289665
14	1996	4.39000E+008	9.89602E+008	7.36669	.263332
15	1997	4.39000E+008	1.09470E+009	7.60608	.239393
16	1998	4.39000E+008	1.19023E+009	7.82371	.21763
17	1999	4.39000E+008	1.27709E+009	8.02155	.197845
18	2000	4.39000E+008	1.35605E+009	8.20141	.179859
19	2001	4.39000E+008	1.42783E+009	8.36492	.163509
20	2002	4.39000E+008	1.49308E+009	8.51357	.148544
21	2003	4.39000E+008	1.55240E+009	8.64869	.135131
22	2004	4.39000E+008	1.60633E+009	8.77154	.122846
23	2005	4.39000E+008	1.65536E+009	8.88322	.111679
24	2006	4.39000E+008	1.69993E+009	8.98474	.101525
25	2007	4.39000E+008	1.74045E+009	9.07704	.0922965

NET PRESENT VALUE = $ 1.74045E+009

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Table F-6

NET PRESENT VALUE
THIS COMPUTATION FOR SCENARIO 6-WITH TOTAL NON-RECURRING
COSTS OF $294 MILLION

INVESTMENT (OUTLAY)=$ 0
NUMBER OF YEARS 25
REQUIRED RATE OF RETURN(DISCOUNT RATE) R= 10 %

CASH FLOW -
OUTFLOWS ARE NEGATIVE

			VALUES OF NET COST OR BENEFIT FOR THE YEAR	CUMULATIVE	DISCOUNT FACTORS
1	1983	-1.80000E+007	-1.63636E+007	.909091	.909091
2	1984	-3.00000E+007	-4.11570E+007	1.73554	.826447
3	1985	-4.00000E+007	-7.12096E+007	2.48685	.751315
4	1986	-1.00000E+008	-1.39511E+008	3.16987	.683014
5	1987	-9.60000E+007	-1.99120E+008	3.79079	.620922
6	1988	8.00000E+007	-1.53962E+008	4.35526	.564474
7	1989	2.10000E+008	-4.61983E+007	4.86842	.513159
8	1990	2.10000E+008	5.17584E+007	5.33493	.466508
9	1991	2.10000E+008	1.40829E+008	5.75902	.424098
10	1992	2.10000E+008	2.21793E+008	6.14457	.385544
11	1993	2.10000E+008	2.95397E+008	6.49506	.350495
12	1994	2.10000E+008	3.62310E+008	6.81369	.318632
13	1995	2.10000E+008	4.23139E+008	7.10336	.289665
14	1996	2.10000E+008	4.78439E+008	7.36669	.263332
15	1997	2.10000E+008	5.28712E+008	7.60608	.239393
16	1998	2.10000E+008	5.74414E+008	7.82371	.21763
17	1999	2.10000E+008	6.15961E+008	8.02155	.197845
18	2000	2.10000E+008	6.53732E+008	8.20141	.179859
19	2001	2.10000E+008	6.88063E+008	8.36492	.163509
20	2002	2.10000E+008	7.19284E+008	8.51357	.148644
21	2003	2.10000E+008	7.47561E+008	8.64869	.135131
22	2004	2.10000E+008	7.73459E+008	8.77154	.122846
23	2005	2.10000E+008	7.96911E+008	8.88322	.111679
24	2006	2.10000E+008	8.18232E+008	8.98474	.101526
25	2007	2.10000E+008	8.37614E+008	9.07704	.0922965

NET PRESENT VALUE = $ 8.37614E+008

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